Original Article

Effect of different scanning threshold triggers on the image quality of brain computed tomography angiography: a randomized controlled trial

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Background: The scanning trigger threshold affects image quality. The aim of this study was to investigate the effect of different scanning trigger thresholds on brain computed tomography angiography (CTA) image quality.

Methods: In this prospective study, 80 patients undergoing brain CTA examinations with dual-layer CT (DLCT) were randomly divided into group A and group B, with 40 patients in each group. In group A, the CT value of the internal carotid artery at the level of the fourth cervical vertebra was monitored, and the scan was initiated once the CT value reached 100 Hounsfield units (HU). In group B, the trigger threshold was set at 60 HU, with all other parameters kept consistent with those of group A. Finally, the image quality of the 50-keV virtual monoenergetic images (VMIs) was evaluated, including the CT values of the internal carotid artery (CT_{ICA}), middle cerebral artery (CT_{MCA}), sinus confluence (CT_{SC}), cerebral white matter (CT_{CWM}), background noise (BN), signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR), and subjective scoring.

Results: All images met the diagnostic imaging requirements. Group B showed significantly lower values than did group A for CT_{ICA} (371.97±51.81 *vs.* 442.64±83.39 HU), CT_{MCA} (345.80±50.72 *vs.* 405.87±82.81 HU), CT_{SC} (90.44±21.30 *vs.* 138.87±37.37 HU), CT_{CWM} (31.98±5.66 *vs.* 38.86±5.68 HU), SNR (108.64±21.05 *vs.* 126.79±30.87), and CNR (98.58±19.72 *vs.* 114.65±29.56) (all P values <0.05) but the value for BN was not significantly different (P>0.05). However, the subjective scores in group B were significantly higher than those

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in group A (χ^2=19.013; P<0.05).

Conclusions: For brain CTA imaging in DLCT (50 keV VMIs), lowering the scan trigger threshold to 60 HU helped to reduce venous artifacts and improve image quality (as evidenced by improved subjective scores) and also suggests the potential for a further reduction of the contrast dose.

Keywords: Brain computed tomography angiography (brain CTA); contrast dose; dual-layer computed tomography (DLCT); image quality; trigger threshold

Submitted Apr 24, 2024. Accepted for publication Nov 14, 2024. Published online Dec 30, 2024.
doi: 10.21037/qims-24-834
View this article at: https://dx.doi.org/10.21037/qims-24-834

Introduction

Brain computed tomography angiography (CTA) is a crucial imaging technique for evaluating cerebral vascular diseases such as acute stroke, aneurysms, and vascular malformations (1,2). During a brain CTA examination, an iodinated contrast agent is injected intravenously by using a high-pressure injector to visualize the cerebral arteries (3,4). However, due to the rapid circulation of cerebral arteries and veins or a late initiation of scans, the contrast agent may prematurely enter the cerebral venous system, causing venous contamination and impairing arterial visualization (5,6). Venous contamination can further lead to a decrease in the quality of vascular images, thereby impacting the diagnosis of certain diseases (3,6,7). Therefore, minimizing venous contamination is essential for improving image quality and diagnostic accuracy.

For brain CTA examination, there are two main scanning methods: test bolus and bolus tracking (8). The bolus-tracking technique, in which the trigger threshold is routinely set at 100–120 Hounsfield units (HU), tends to provide better visualization of cerebral arteries with less venous interference (7,9). However, in spectral scanning mode, dual-layer computed tomography (DLCT) can reconstruct 161 virtual monochromatic images (VMIs) within the range of 40 to 200 keV. The VMIs at low kiloelectron volt (keV) levels can enhance the CT values of cerebral arteries and veins, with the enhancement becoming more pronounced at lower keV levels (10,11). If the triggering threshold remains set at 100–120 HU for lower keV VMIs (such as 50-keV VMIs), the faintly visible cerebral veins will also be enhanced, resulting in venous contamination and detrimental effects on image quality. There is also a dearth of literature concerning the effect of the trigger threshold on image quality.

Therefore, building on this understanding, this study aimed to clarify the effects of reducing the trigger threshold to 60 HU in brain CTA imaging and of initiating the scan sooner to reduce contrast accumulation in cerebral veins, particularly as it relates to minimizing venous contamination, enhancing overall image quality, and preserving arterial observation. We present this article in accordance with the CONSORT reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-24-834/rc).

Methods

Study population

This prospective study initially enrolled 102 patients who were admitted to Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, from January 2023 to October 2023, but only 80 patients were ultimately included. The study flowchart is shown in *Figure 1*. The inclusion criteria were as follows: (I) clinical suspicion or diagnosis of cerebrovascular disease, manifesting symptoms such as dizziness, headache, and limb movement disorders; (II) absence of a history of iodine contrast agent allergy; and (III) age >18 years. The exclusion criteria were as follows: (I) a history of allergy to iodine contrast agent; (II) pregnancy or lactation; (III) severe hepatic or renal dysfunction; (IV) asthma or severe heart failure; (V) hyperthyroidism; and (VI) cachexia. This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013), and was not registered on any platform due to it being a small-sample exploratory study of imaging technology. This study was approved by the Ethics Committee of Union Hospital, Tongji Medical College, Huazhong University of Science and Technology (No. 0201-01), and all patients provided written informed consent.

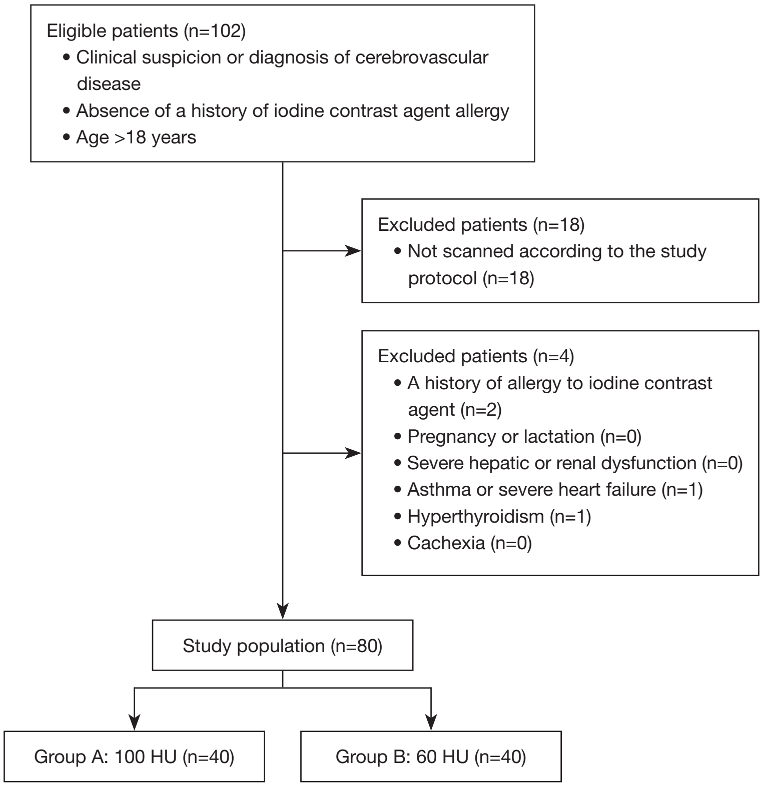

Figure 1 Flowchart of the inclusion and exclusion of the study population. HU, Hounsfield unit.

Examination methods and scanning parameters

According to a random number table method, 80 patients undergoing brain CTA examinations were randomly assigned to either group A or group B, with 40 participants in each groups. Prior to the examination, patients were instructed to remove any metal objects from their head, assume a supine position, immobilize their heads, place their hands at their sides, and protect nontarget areas with a lead shield. In both groups, a DLCT system (IQon Spectral CT, Philips Healthcare, Best, The Netherlands) was used to scan patients, with the bolus-tracking technique also being applied. In group A, the CT value of the internal carotid artery at the level of the fourth cervical vertebra was monitored, and the scan was initiated with a 3-second delay once the CT value reached 100 HU. In group B, the trigger threshold was set to 60 HU, and the other settings were identical to those in group A. The image reconstruction was performed using single-energy projection spectral reconstruction (Recon Mode: spectral, level =1) to obtain 50-keV VMIs for both objective and subjective image evaluations. The basic scanning parameters included a scan range from the base to the top of the skull, a tube voltage of 120 kVp, a tube current adjusted by automatic tube current modulation technology, a collimator width of 64×0.625 mm, a pitch of 0.985, an X-ray tube rotation speed of 0.5 s/rotation, a matrix of 512×512, a slice thickness and interval of 1 mm, a window width of 360 HU, and a window level of 60 HU.

Contrast agent injection protocol

A high-pressure injector (Medrad StellantD-CE, Bayer AG, Leverkusen, Germany) was used for contrast agent administration. Iodixanol (350 mgI/mL; Jiangsu Hengrui Medicine Co., Ltd., Lianyungang, China), an iodine-based contrast agent, was administered via the right median cubital vein. A standardized contrast agent injection protocol was conducted for groups, with a constant injection duration of 10 seconds. The injection rate was tailored based on the patient's weight as follows: 40 kg ≤ body weight <50 kg, 26 mL of contrast medium injected at 2.6 mL/s; 50 kg ≤ body weight <60 kg, 29 mL injected at 2.9 mL/s; 60 kg ≤ body weight <70 kg, 31 mL injected at

3.1 mL/s; 70 kg ≤ body weight <80 kg, 34 mL injected at 3.4 mL/s; and 80 kg ≤ body weight <90 kg, 37 mL injected at 3.7 mL/s. Subsequently, 20 mL of normal saline was injected at the corresponding rate.

Objective evaluation

The 50-keV VMIs were imported into a postprocessing workstation (Philips Healthcare), and the CT values of the cavernous segment of the right internal carotid artery (CT_{ICA}), M1 segment of the right middle cerebral artery (CT_{MCA}), sinus confluence (CT_{SC}), and adjacent cerebral white matter of the lateral ventricle (CT_{CWM}) on cross-sectional thin-layer images were measured using circular regions of interest (ROIs). The ROI area, ranging from 0.02 to 0.10 cm^2, constituted half to two-thirds of the cross-sectional area of the blood vessel or cerebral white matter. To minimize partial volume effects, the measurement of vascular CT values omitted vessel walls, calcifications, and atherosclerotic plaques. In the measurement of CT_{CWM}, blood vessels, gray matter, lateral ventricles, and lesions were similarly excluded. All the above data were repeatedly measured three times and averaged. The standard deviation (SD) of the ROI_{CWM} was used as the background noise (BN). Both the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were then calculated as follows: SNR = CT_{MCA}/BN; CNR = (CT_{MCA} – CT_{CWM})/BN. Finally, the CT_{ICA}, CT_{MCA}, CT_{SC}, CT_{CWM}, BN, SNR, and CNR values were compared between the two groups.

Subjective evaluation

According to volume rendering (VR), maximum intensity projection (MIP), and curved planar reformation (CPR) images, two senior radiologists who were unaware of the patients' information and scanning parameters blindly evaluated the images from both groups. In cases of disagreement, a final overall score was determined after discussion. The scheme for the scoring was as follows: 5 points for clear visibility of the main cerebral blood vessels and their fifth level branches, including small distant branches; 4 points for clear visibility of the main cerebral blood vessels and their fourth level branches, with small distant branches being less clear; 3 points for faint vascular imaging, revealing the main cerebral blood vessels and their third level branches, with poor visibility of the smaller vessels; 2 points for faint vascular imaging, revealing the main cerebral blood vessels and their second level branches, with the smaller vessels being unclear; and 1 point for faint vascular imaging, only depicting cerebral blood vessels below the second level branches, deemed entirely inadequate for disease diagnosis. A deduction of 1 point was made in the presence of venous contamination (CT_{SC} >100 HU); otherwise, no points were deducted.

Statistical analysis

SPSS 26 (IBM Corp., Armonk, NY, USA) was used for statistical analysis. The continuous data are presented as the mean ± SD, and the categorical data are presented as the number and percentage. For quantitative data adhering to a normal distribution, the *t*-test was applied. For nonnormally distributed data, the Mann-Whitney test was employed. The chi-square (χ^2) test was used for categorical data. Differences were considered statistically significant at $P<0.05$. The agreement between the subjective scores assigned by two radiologists was evaluated using the kappa test, with $\kappa<0.40$ indicating poor agreement, $0.40\leq\kappa\leq0.75$ indicating moderate agreement, and $\kappa>0.75$ indicating strong agreement.

Results

Patient information

The basic demographic data for the two groups are presented in *Table 1*. No statistically significant differences were observed in terms of gender, age, or body mass index (BMI) between the two groups (all P values >0.05), indicated comparable patient characteristics between the groups.

Objective evaluation

As shown in *Table 2*, statistical differences were noted in the CT_{ICA}, CT_{MCA}, CT_{SC}, CT_{CWM}, SNR, and CNR values between the two groups (all P values <0.05) but for BN. Among these parameters, group A exhibited higher CT_{ICA}, CT_{MCA}, SNR, and CNR values compared to group B, suggesting enhanced arterial visualization in group A. Additionally, the CT_{SC} value in group A was higher than that in Group B, suggesting slightly higher venous contamination in group A.

Subjective evaluation

As shown in *Table 3* and *Figures 2,3*, neither of the two

Table 1 Clinical characteristics of patients

Variables	Group A (n=40)	Group B (n=40)	Test value	P value
Sex			χ^2=0.213	0.644
Male	16 (40.0)	14 (35.0)		
Female	24 (60.0)	26 (65.0)		
Age (years)	58.53±9.22	57.05±17.14	t=0.479	0.633
BMI (kg/m^2)	24.43±3.49	23.01±3.85	t=1.726	0.088

Continuous data are presented as the mean ± standard deviation; categorical data are presented as the number (percentage). BMI, body mass index.

Table 2 The comparison of objective evaluation for image quality

Variables	Group A	Group B	Test value	P value
CT_{ICA} (HU)	442.64±83.39	371.97±51.81	t'=4.553	<0.001
CT_{MCA} (HU)	405.87±82.81	345.80±50.72	t'=3.912	<0.001
CT_{SC} (HU)	138.87±37.37	90.44±21.30	t'=7.121	<0.001
CT_{CWM} (HU)	38.86±5.68	31.98±5.66	t=5.431	<0.001
BN	3.27±0.48	3.25±0.51	t=0.227	0.821
SNR	126.79±30.87	108.64±21.05	t'=3.072	0.003
CNR	114.65±29.56	98.58±19.72	t'=2.860	0.005

Data are expressed as the mean ± standard deviation. CT, computed tomography; HU, Hounsfield unit; CT_{ICA}, CT value of the internal carotid artery; CT_{MCA}, CT value of the middle cerebral artery; CT_{SC}, CT value of the sinus confluence; CT_{CWM}, CT value of the cerebral white matter; BN, background noise; SNR, signal-to-noise ratio; CNR, contrast-to-noise ratio.

Table 3 Subjective scoring results (cases)

Subjective scoring	Group A (n=40)	Group B (n=40)	χ^2 value	P value
5 points	6 (15.0)	25 (62.5)	19.013	<0.05
4 points	34 (85.0)	15 (37.5)		
3 points	0	0		
2 points	0	0		
1 point	0	0		

Categorical data are presented as the number (percentage).

groups had CTA images rated below 4 points, and all images satisfied the criteria for diagnostic quality. A statistically significant difference was observed in the image scores between the two groups (χ^2=19.013; P<0.05), with group B (4 points in 15 cases; 5 points in 25 cases) outperforming group A (4 points in 34 cases; 5 points in 6 cases). The agreement between the two radiologists was strong (κ=0.897).

Discussion

The appropriate selection of the triggering threshold is crucial for ensuring high image quality, as this aids in the clinical assessment of intracranial aneurysms, vascular stenosis, occlusions, and vascular malformations (12-14). In this study, two different triggering thresholds, 100 and 60 HU, were established for brain CTA imaging, which

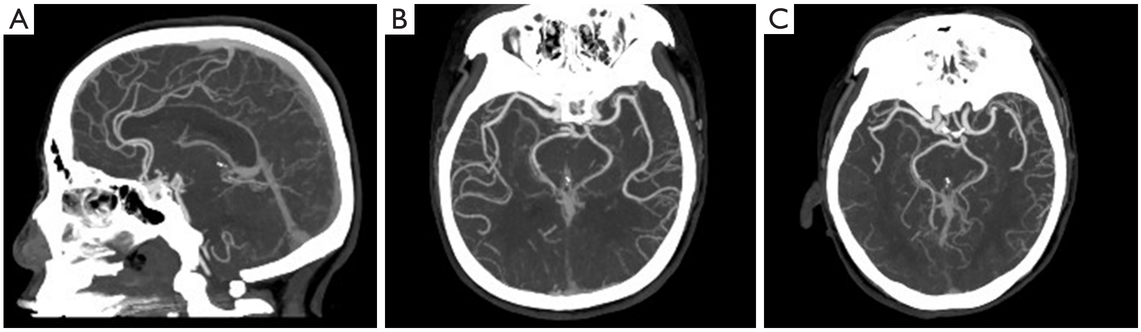

Figure 2 Case presentation from group A. A 60-year-old female, weighing 70 kg, whose contrast dose was 31 mL. The image quality score was rated at 4 points: (A) the anterior cerebral artery, (B) middle cerebral artery, and (C) posterior cerebral artery were clearly visualized on the 50-keV VMIs, although venous contamination was observed. VMI, virtual monoenergetic image.

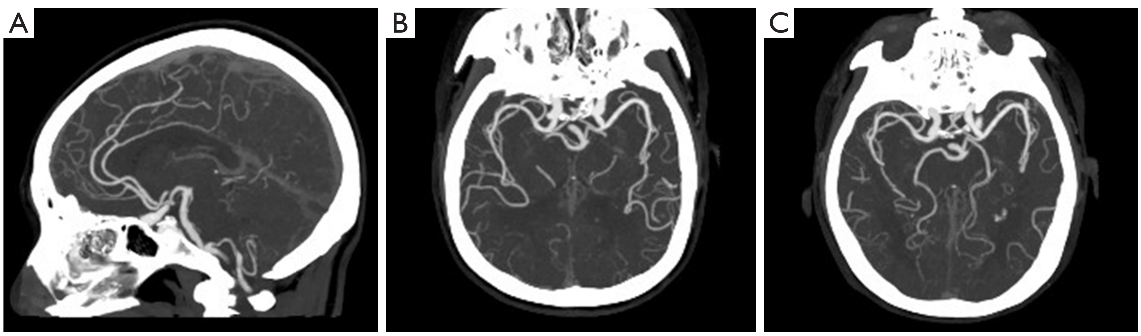

Figure 3 Case presentation from Group B. A 68-year-old female, weighing 55 kg, whose contrast dose was 29 mL. The image quality score was rated at 5 points: (A) the anterior cerebral artery, (B) middle cerebral artery, and (C) posterior cerebral artery were clearly visualized on the 50-keV VMIs, with no venous contamination. VMI, virtual monoenergetic image.

was followed by a comparative analysis of the vascular image quality of 50-keV VMIs in both groups. The findings suggest that lowering the scanning triggering threshold reduces the CT values of cerebral arteries and veins, the SNR, and the CNR. Meanwhile, from the standpoint of subjective evaluation, reducing the scanning triggering threshold may be advantageous in diminishing venous artifacts and enhancing image quality.

The DLCT scanner is equipped with spatially equivalent upper and lower detectors: the upper detector employs a scintillation crystal derived from the rare metal yttrium, designed to absorb only low-energy photons and allow high-energy photons to pass through; the lower detector comprises a rare earth ceramic detector that captures high-energy photons. This innovative dual-layer detector design demonstrates the "three same" principles in energy inspection, namely simultaneous acquisition, a single source, and uniform direction (15,16). A key benefit of this feature is the implementation of anticorrelated noise-suppression technology, which guarantees consistently low noise levels across all 161 VMIs spanning from 40 to 200 keV, achieving notably reduced noise even in the 40-keV VMIs (11,17). Previous studies have indicated that 50-keV VMIs provide optimal image quality for brain CTA imaging (18-20). Therefore, in this study, the 50-keV VMIs were also used for image quality assessment and disease diagnosis in both groups.

The optimal CT value range within the vascular lumen has been identified as 300–450 HU. CT values below this range detract from the depiction of vascular details, while values above this range may compromise the visualization of atherosclerotic plaques and the analysis of vascular stenosis (21-24). In this study, the CT_{ICA}, CT_{MCA}, SNR, and CNR values of group B were marginally lower than those of group A. Although the visualization of the cerebral arteries in group B might not have been as distinct as that in group

A, the CT_{MCA} for both groups remained within the optimal CT value range. This ensured effective representation of the main trunk and various branches of the cerebral arteries, satisfying the requirements for the imaging diagnosis of diseases. Additionally, previous studies have typically focused on subjectively assessing the depiction of cerebral arteries, overlooking the impact of venous enhancement on image quality. By evaluating both cerebral arterial and venous visualization in this study, we could obtain a more comprehensive reflection of the image quality. Moreover, the inclusion of venous contamination as a factor in the image scoring criteria led to higher image scores for group B compared to group A.

In brain CTA imaging, a large amount of contrast agent needs to be injected at a relatively fast flow rate to maintain the iodine concentration in the blood vessels for about 10 seconds (5,10). In this study, group B (trigger threshold: 60 HU) had the CTA scanning sequence initiated approximately 2 seconds earlier than that in group A (trigger threshold: 100 HU), indicating that the scan was activated as the contrast agent arrived at the target vessels rather than when the contrast concentration peaked. This suggests that group B had optimized use of the contrast agent, potentially shortening the duration of the contrast agent's injection by approximately 2 seconds. The average injection rate for group B was 3.1 mL/s, and it could reduce the contrast agent dose by approximately 6.2 mL. However, further experiments to confirm the viability of shortening the contrast agent's injection time were not conducted in this study. This would represent a subsequent step in further decreasing the contrast agent volume within the existing low-dose scanning framework, potentially diminishing the risk of adverse contrast reactions and contrast-induced nephropathy.

This study was subject to certain limitations: (I) the small sample size might have introduced selection bias. (II) Due to limitations such as the contrast agent dose and radiation exposure, it was difficult to conduct self-controlled experiments, and there were differences in individual cardiac function or hemodynamics; therefore, our conclusions are relative. (III) The possibility for further reduction in contrast agent dosage needs to be validated through experimental design. (IV) With group B's trigger threshold set at 60 HU, which closely approximates the baseline CT value of blood vessels (50 HU), the precise placement of the ROI on the target vessel is essential to preventing inadvertent triggering and potential examination failures.

Conclusions

When 50-keV VMIs are used in DLCT for brain CTA imaging, lowering the scan trigger threshold to 60 HU can reduce venous contamination without affecting arterial visualization and improve image quality. Furthermore, this adjustment may also shorten the contrast agent's injection duration, offering the potential to further decrease the contrast agent dosage.

Acknowledgments

We appreciate the contributions of all authors for participating in data analysis, drafting, and critical revisions.
Funding: This research was funded by the special funds for "Pharmacy-Technology-Nursing" of Union Hospital (No. 2023XHYN104).

Footnote

Reporting Checklist: The authors have completed the CONSORT reporting checklist. Available at https://qims.amegroups.com/article/view/10.21037/qims-24-834/rc

Trial Protocol: Available at https://qims.amegroups.com/article/view/10.21037/qims-24-834/tp

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-24-834/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Institutional Review Board of Union Hospital, Tongji Medical College, Huazhong University of Science and Technology (No. 0201-01), and all patients provided written informed consent.

References

1. Jadhav AP, Jovin TG. Vascular imaging of the head and neck. Semin Neurol 2012;32:401-10.
2. Salehi L, Jaskolka J, Ossip M, Phalpher P, Valani R, Mercuri M. Utilization of CT angiography of the head and neck in the era of endovascular therapy for acute ischemic stroke: a retrospective study. Emerg Radiol 2022;29:291-8.
3. Enterline DS, Kapoor G. A practical approach to CT angiography of the neck and brain. Tech Vasc Interv Radiol 2006;9:192-204.
4. Kim HJ, Yoon DY, Kim ES, Yun EJ, Jeon HJ, Lee JY, Cho BM. 256-row multislice CT angiography in the postoperative evaluation of cerebral aneurysms treated with titanium clips: using three-dimensional rotational angiography as the standard of reference. Eur Radiol 2020;30:2152-60.
5. Cheng HW, Geng JH, Tan ZW, Wu WZ, Hu XL, Gong JF, Shen J, Xu J, She M. The Application Value of Gemstone Spectral Imaging (GSI) Combined with an 80 mm Wide-body Detector in Head-neck CTA. Curr Med Imaging 2023. [Epub ahead of print]. doi: 10.2174/0115734056186139231101063906.
6. Hingwala DR, Thomas B, Kesavadas C, Kapilamoorthy TR. Suboptimal contrast opacification of dynamic head and neck MR angiography due to venous stasis and reflux: technical considerations for optimization. AJNR Am J Neuroradiol 2011;32:310-4.
7. Chen Y, Zhang X, Xue H, Zhu Y, Wang Y, Li Y, Zhang Z, Jin Z. Head and neck angiography at 70 kVp with a third-generation dual-source CT system in patients: comparison with 100 kVp. Neuroradiology 2017;59:1071-81.
8. Cademartiri F, van der Lugt A, Luccichenti G, Pavone P, Krestin GP. Parameters affecting bolus geometry in CTA: a review. J Comput Assist Tomogr 2002;26:598-607.
9. Zheng H, Yang M, Jia Y, Zhang L, Sun X, Zhang Y, Nie Z, Wu H, Zhang X, Lei Z, Jing W. A Novel Subtraction Method to Reduce Metal Artifacts of Cerebral Aneurysm Embolism Coils. Clin Neuroradiol 2022;32:687-94.
10. Lu XP, Wang Y, Chen Y, Wang YL, Xu M, Jin ZY. Quality of Images Reconstructed by Deep Learning Reconstruction Algorithm for Head and Neck CT Angiography at 100 kVp. Zhongguo Yi Xue Ke Xue Yuan Xue Bao 2023;45:416-21.
11. Nagayama Y, Iyama A, Oda S, Taguchi N, Nakaura T, Utsunomiya D, Kikuchi Y, Yamashita Y. Dual-layer dual-energy computed tomography for the assessment of hypovascular hepatic metastases: impact of closing k-edge on image quality and lesion detectability. Eur Radiol 2019;29:2837-47.
12. Yuan D, Li L, Zhang Y, Qi K, Zhang M, Zhang W, Lyu P, Zhang Y, Gao J, Liu J. Image quality improvement in head and neck CT angiography: Individualized post-trigger delay versus fixed delay. Eur J Radiol 2023;168:111142.
13. Willems PW, Taeshineetanakul P, Schenk B, Brouwer PA, Terbrugge KG, Krings T. The use of 4D-CTA in the diagnostic work-up of brain arteriovenous malformations. Neuroradiology 2012;54:123-31.
14. Ellis JA, Nossek E, Kronenburg A, Langer DJ, Ortiz RA. Intracranial Aneurysm: Diagnostic Monitoring, Current Interventional Practices, and Advances. Curr Treat Options Cardiovasc Med 2018;20:94.
15. Si-Mohamed SA, Boccalini S, Lacombe H, Diaw A, Varasteh M, Rodesch PA, et al. Coronary CT Angiography with Photon-counting CT: First-In-Human Results. Radiology 2022;303:303-13.
16. Hua CH, Shapira N, Merchant TE, Klahr P, Yagil Y. Accuracy of electron density, effective atomic number, and iodine concentration determination with a dual-layer dual-energy computed tomography system. Med Phys 2018;45:2486-97.
17. Kalender WA, Klotz E, Kostaridou L. An algorithm for noise suppression in dual energy CT material density images. IEEE Trans Med Imaging 1988;7:218-24.
18. Dunning CAS, Rajendran K, Inoue A, Rajiah P, Weber N, Fletcher JG, McCollough CH, Leng S. Optimal Virtual Monoenergetic Photon Energy (keV) for Photon-Counting-Detector Computed Tomography Angiography. J Comput Assist Tomogr 2023;47:569-75.
19. Fransson V, Mellander H, Ramgren B, Andersson H, Arena F, Ydström K, Ullberg T, Wassélius J. Image quality of spectral brain computed tomography angiography using halved dose of iodine contrast medium. Neuroradiology 2023;65:1333-42.
20. Ren H, Zhen Y, Gong Z, Wang C, Chang Z, Zheng J. Feasibility of low-dose contrast media in run-off CT angiography on dual-layer spectral detector CT. Quant Imaging Med Surg 2021;11:1796-804.
21. Sugimoto K, Fujiwara Y, Oita M, Kuroda M. Estimating the differences between inter-operator contrast enhancement in cerebral CT angiography. Med Phys 2023;50:7934-45.

22. Mohan S, Agarwal M, Pukenas B. Computed Tomography Angiography of the Neurovascular Circulation. Radiol Clin North Am 2016;54:147-62.
23. Kayan M, Demirtas H, Türker Y, Kayan F, Çetinkaya G, Kara M, Orhan Çelik A, Umul A, Yılmaz Ö, Recep Aktaş A. Carotid and cerebral CT angiography using low volume of iodinated contrast material and low tube voltage. Diagn Interv Imaging 2016;97:1173-9.
24. Ramgren B, Björkman-Burtscher IM, Holtås S, Siemund R. CT angiography of intracranial arterial vessels: impact of tube voltage and contrast media concentration on image quality. Acta Radiol 2012;53:929-34.

Cite this article as: Xu J, Shen J, Dong Q, Gui S, Wang J, Lei ZQ, Hu XL, Luo K. Effect of different scanning threshold triggers on the image quality of brain computed tomography angiography: a randomized controlled trial. Quant Imaging Med Surg 2025;15(1):515-523. doi: 10.21037/qims-24-834