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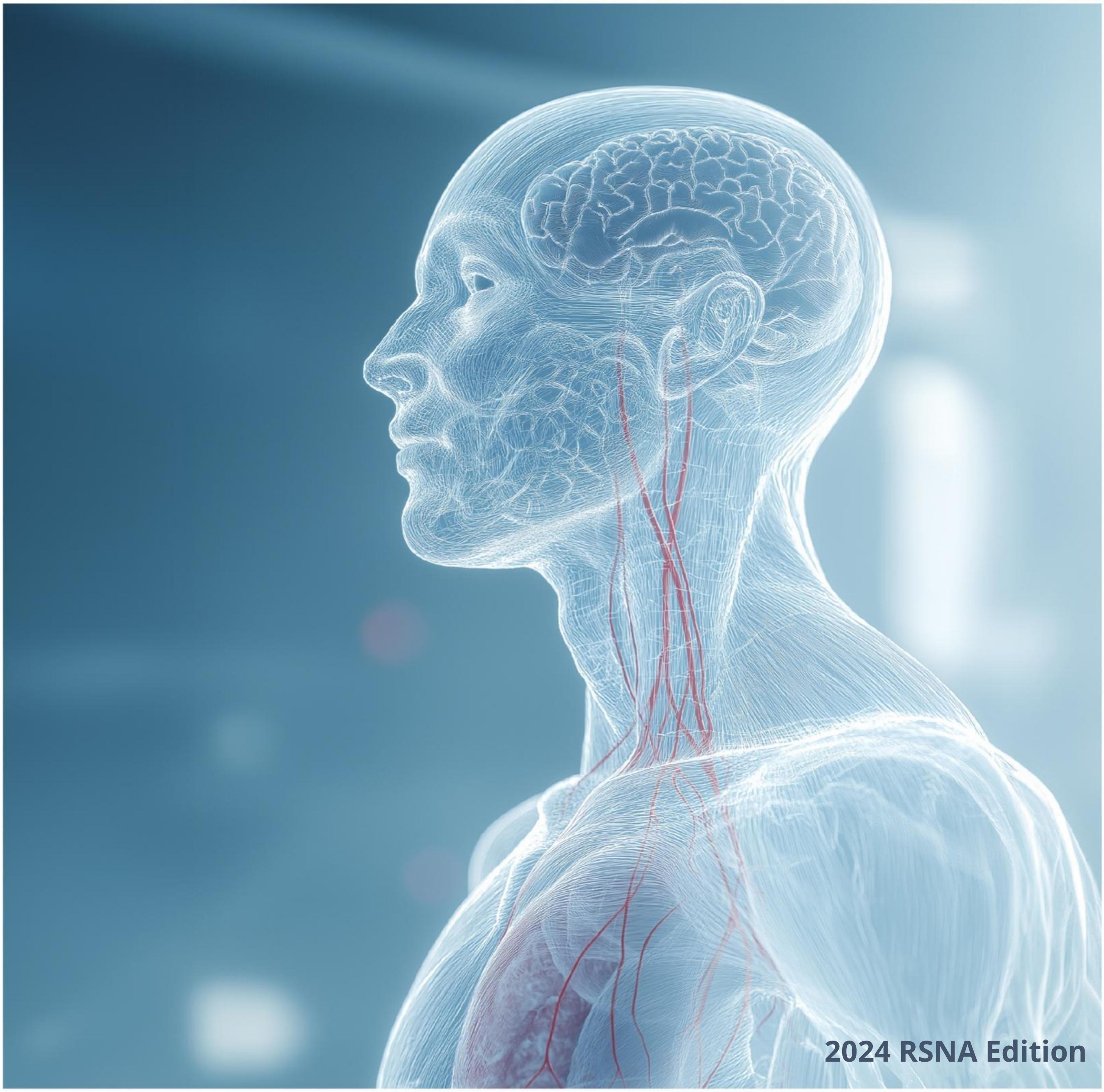

2024 RSNA Edition

Issue Highlights

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One-stop dynamic whole-brain CT perfusion with a 320-row scanner for patients with acute ischemic stroke and the clinical value of artificial intelligence iterative reconstruction

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1. Introduction

Acute ischemic stroke (AIS) is the leading cause of morbidity and mortality worldwide, accounting for over 80% of all stroke incidents (1). Previous research has indicated that patients who present with salvageable brain or adequate collaterals and undergo early recanalization could have an improved clinical outcome (2). The risk of a poor clinical outcome could increase by around 14% with every 30-minute delay in treatment (3). Therefore, it is essential to identify the salvageable ischemic brain tissue quickly and reliably using an optimal imaging technique.

Many randomized controlled trials have confirmed the importance of computed tomography perfusion (CTP) in diagnosing AIS (4). Specifically, CTP can provide a quantitative assessment of the ischemic core, tissue at risk, and cerebral hemodynamic status (5), benefiting patients undergoing endovascular thrombectomy. In addition, CT angiography (CTA) derived from CTP data can provide intracranial status and assessment for a possible underlying vessel occlusion or other vascular pathologies (6). However, since CTP requires multi-phase scans, the accumulated radiation burden raises a considerable concern (7). In the past few years, considerable efforts have been devoted to minimizing the radiation dose for CTP scans. With the development of their 320-row scanner (uCT 960+, United Imaging Healthcare, Shanghai, China), United Imaging has made it possible to perform one-stop dynamic whole-brain CTP imaging with phase-specific tube current modulation settings to allow the user to effectively optimize and reduce the radiation dose for CTP scans. With the one-stop protocol, brain CTP and CTA images can be obtained simultaneously within a single examination, requiring only a single injection of contrast medium.

Moreover, with the recent rapid developments in artificial intelligence technologies and algorithms, deep learning-based image reconstruction (DLR) has gained considerable interest for the field of CT imaging demonstrating the potential for image quality improvements and low dose imaging capabilities (8). United Imaging has recently introduced an artificial intelligence iterative reconstruction (AIIR, United Imaging Healthcare, Shanghai, China) algorithm (9), which has been developed to combine the advantages of traditional model-based iterative reconstruction algorithms to accurately characterizing image detail and perform low dose imaging with the ability of a convolution neural network CNN to robustly handle the expected image noise and texture. Previous studies using AIIR have provided remarkable outcomes showing improved diagnostic confidence and the ability to perform low dose imaging for abdominal scans, pulmonary and aortic CT angiography and ultra-low dose lung screening applications (10-13). In this work we plan to investigate the ability of AIIR to improve the image quality of CTP scans providing additional clinical value of CT perfusion-derived CTA.

Our study aims to test the reliability of one-stop dynamic whole-brain CTP with a 320-row scanner for AIS patients, and the feasibility of replacing routine CTA with perfusion-derived CTA reconstructed with AIIR for AIS patients.

2. Materials and Methods

2.1 Study Population

The Medical Ethics Committee of our institution approved this retrospective study, eliminating the need for written informed consent.

From February to March 2024, a total of 42 patients with suspected AIS who underwent a one-stop dynamic whole-brain CTP followed by a routine craniocervical CTA examination were enrolled in this study. Seven cases were excluded due to cerebral hemorrhage. Ten cases were excluded due to a combination with other diseases. The final set consisted of 25 patients with confirmed AIS.

2.2 Imaging Protocol and Reconstruction

All imaging procedures were performed using the 320-row detector CT (uCT 960+, United Imaging Healthcare, Shanghai, China). As shown in Figure 1, the entire one-stop dynamic whole-brain CTP protocol consisted of the following five stages (19 phases): (1) Stage 1 (non-contrast), 150 mAs, 1 phase, 3.0s interval; (2) Stage 2 (flow phases), 75 mAs, 3 phases, 2.0s intervals; (3) Stage 3 (arterial phases, boosted for CTA acquisition), 150 mAs, 5 phases, 2.0s intervals; (4) Stage 4 (venous phases), 75 mAs, 4 phases, 2.0s intervals and (5) Stage 5 (washout phases), 5 mAs, 6 phases, 5.0s intervals. The remaining parameters were kept consistent for each phase: 100 kVp, 0.5s rotation time, and 16 cm z-coverage. The scans were initiated 7.0 s after the injection of iodinated contrast medium.

The routine craniocervical CTA images were acquired 5 minutes after the CTP scan with the following helical scanning parameters: 100 kVp, 240 mAs, 80mm longitudinal collimation, 0.89 pitch, and 0.5s rotation time. The acquisition was triggered using a bolus-tracking technique, initiated 3.6s after the CT value in the level of the aortic arch reached the preset 150 Hounsfield units (HU).

All CTP images were reconstructed with hybrid iterative reconstruction (HIR, United Imaging Healthcare, Shanghai, China), with the slice thickness/increment of 5.0/5.0 mm for further CTP parameter calculations. CTP-derived CTA images were extracted from the CTP scan using the peak arterial phase in stage 3 and reconstructed with AIIR (Group A), with the slice thickness/increment of 1.0/1.0 mm for further vessel evaluation. The routine craniocervical CTA images were reconstructed with HIR, with the slice thickness/increment of 1.0/1.0 mm (Group B).

The volume CT dose index (CTDIvol, mGy) and dose length product (DLP, mGy·cm) were recorded for all scans. The effective dose (ED, mSv) was calculated as the DLP multiplied by the conversion factor of 0.0021 $\text{mSv}\cdot\text{mGy}^{-1}\cdot\text{cm}^{-1}$ (14)

2.3 Perfusion Parameter Calculation

All CTP images were transferred to a clinical workstation (uWS-CT, United Imaging Healthcare, Shanghai, China) for perfusion parameter calculations, where the post-processing software corrects motion, removes background, selects the arterial input function (AIF) and venous input function (VIF), and ultimately generates perfusion parametric maps using the deconvolution method previously described in the literature (15) which are then overlaid on the source CTP images. The perfusion parameters generated include cerebral blood flow (CBF), cerebral blood volume (CBV), mean transit time (MTT), time to peak (TTP), and time-to-maximum of the residual function (Tmax). Areas with a decrease of CBF and/or CBV, or areas with an increase of MTT, TTP and/or Tmax indicate abnormal perfusion.

One radiologist was asked to draw a region of interest (ROI) within the core infarction area, while avoiding the blood vessels, brain sulci and gyri. This ROI was copied to the contralateral side using the midline of the brain as an axis of symmetry to obtain an ROI in a healthy area. The perfusion parameters of the ROI for the core infarction area and the corresponding ROI of the normal healthy area on the contralateral side were recorded.

2.4 Perfusion-derived CTA Image Quality Evaluation

For the CTP-derived CTA images (Group A) and the routine craniocervical CTA images (Group B). Two radiologists were independently asked to locate and evaluate the responsible vessels where the vessel occlusion was defined with a focal loss of vascular opacity without distal vessel delineation. They also independently graded the subjective image quality, including image noise, sharpness of the vascular edge, and small vessel visibility, each using a five-point Likert scale (1: poor, 5: excellent) for images in both Group A and B.

In addition, For the Group A and Group B images, the objective image noise was measured by placing an ROI on the internal carotid artery (ICA), the middle cerebral artery M1 segment (MCA-M1), and the basilar artery (BA). The contrast-to-noise ratio (CNR) between the three arteries relative to brain parenchyma were calculated by:

$$\text{CNR} = (HU_{artery} - HU_{parenchyma}) / \sqrt{({SD_{artery}}^2 + {SD_{parenchyma}}^2)/2}$$

where HU and SD denote the mean and standard deviation of CT value within the ROI, respectively.

2.5 Statistics Analysis

Statistical analysis was performed using IBM SPSS Statistics 27.0 (IBM Corp., Armonk, NY, USA). Continuous variables were presented as mean ± standard deviation (SD) or median and interquartile range (IQR) depending on the normality of the data. The normality was examined using the Kolmogorov-Smirnov test. For data with normal distribution, the student's t-test was used, otherwise, the Wilcoxon signed-rank test was used. Categorical variables were expressed as numbers and percentages, where the difference was analyzed using the Wilcoxon signed-rank test. A two-tailed $p < 0.05$ was considered statistically significant.

3. Results

3.1 Patient Characteristics and Radiation Dose

A total of 25 patients (mean age: 67.5 ± 12.5 y, range 50-90 y, male/female: 13/12) with confirmed AIS were enrolled in the evaluation. The mean CTDIvol of the one-stop dynamic whole-brain CTP protocol was 163.2 ± 0.1 mGy, which was comparable to that of previously published CTP protocols with a fixed tube voltage (80 kVp) and tube current (150 mAs) (16). The ED of the one-stop dynamic whole-brain CTP protocol was 5.5 ± 0.0 mSv, which was lower than the cumulative radiation dose (> 10 mSv) for whole-brain CTP and CTA scans reported in the literature (17). For routine craniocervical CTA, the mean CTDIvol and DLP were 9.7 ± 0.0 mGy and 454.7 ± 24.9 mGy/cm, respectively.

3.2 Perfusion Parameter

As shown in Table 1, the perfusion parameters were significantly different between the core infarction area and the contralateral healthy area (all $p < 0.05$). Compared with the contralateral healthy area, CBF and CBV in the core infarction area were significantly decreased, while TTP, MTT and Tmax were significantly increased. One representative case is shown in Figure 2.

3.3 Perfusion-derived CTA Image Quality

The diagnosis of responsible vessels was consistent between Groups A and B, where a total of 13 patients were diagnosed with complete vascular occlusion, while the other 12 patients were diagnosed with above-moderate vascular stenosis.

Both Group A and B demonstrate good diagnostic quality, as evaluated by the scores of the three subjective metrics with all mean scores exceeding 4. This implies that the CTP-derived CTA with AIIR could provide a comparably good diagnostic quality as the routine CTA with HIR. When comparing group A and B, the likert scores were significantly higher in Group B than those in Group A (all $p < 0.05$), where the average scores were 4.96 ± 0.20 versus 4.00 ± 0.00, 4.96 ± 0.20 versus 4.71 ± 0.55 and 4.92 ± 0.28 versus 4.04± 0.20 for image noise, sharpness of the vascular edge and small vessel visibility, respectively. Among all metrics, the improvement of the subjective score seemed to be most profound on the small vessel visibility. As shown in Figure 3, Group A provided sharper arterial boundaries and improved intracranial artery visualization, especially for small arterial details on distal second-order branches with reduced image noise than Group B.

AIIR showed a remarkable capability for image noise suppression, leading to a significantly higher CNR (all $p < 0.001$) for ICA, MCA-M1, and BA in Group A (28.7 ± 10.5, 12.9± 7.2, and 15.0 ± 10.6) than those in Group B (17.8 ± 8.9, 7.5 ± 3.5, and 9.1 ± 7.5).

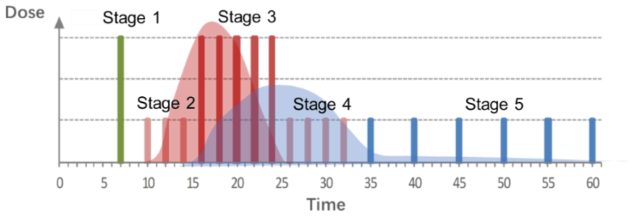

Figure 1. Acquisition protocol of the one-stop dynamic whole-brain CTP. The red and light blue curves mean the arterial input function and venous input function curves, respectively.

Table 1. Comparison of perfusion parameters between the infarct lesions and their corresponding contralateral healthy regions

Perfusion parameter	Core infarction area	Contralateral healthy area	p value
CBV (ml/100 g)	1.1 ± 0.4	2.7 ± 2.2	< 0.05
CBF [ml/100 g/min]	7.6 ± 4.5	13.0 ± 6.0	< 0.05
MTT (s)	15.9 ± 6.0	11.0 ± 1.7	< 0.05
TTP (s)	30.3 ± 10.2	23.3 ± 7.4	< 0.05
Tmax (s)	10.5 ± 5.2	2.3 ± 1.0	< 0.05

Note: CBV, cerebral blood volume; CBF, cerebral flood volume; MTT, mean transit time; TTP, time to peak; Tmax, time-to-maximum of the residual function

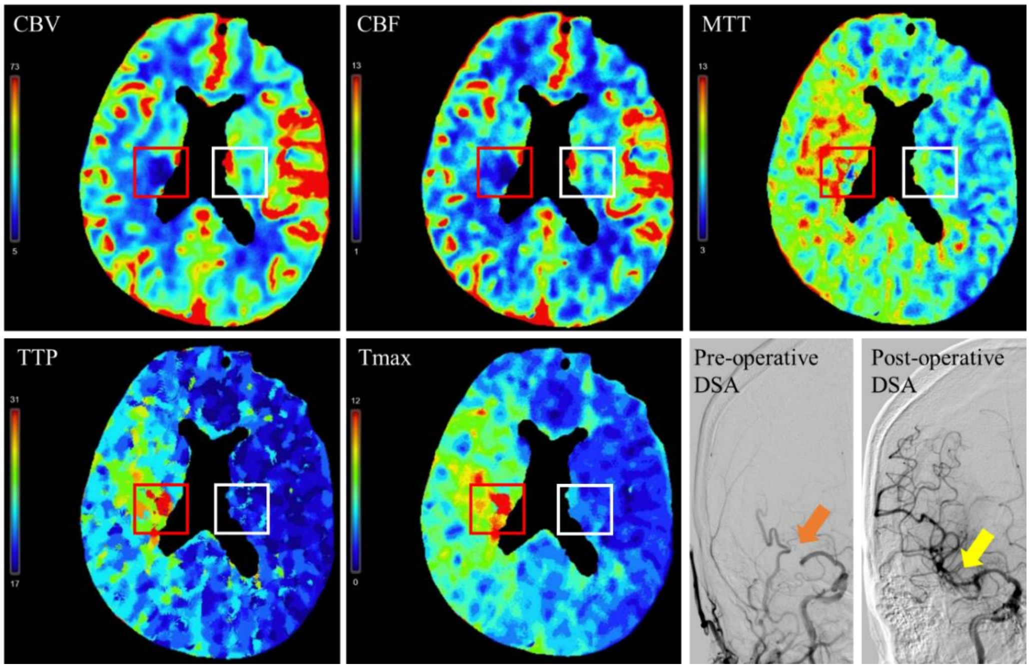

Figure 2. Perfusion parameter maps from a 68-year-old man with acute occlusion of the right middle cerebral artery (R-MCA) confirmed by digital subtraction angiography (DSA), where the R-MCA was totally occluded (orange arrow) in pre-operative DSA while was recanalized (yellow arrow) in post-operative DSA. The perfusion parameters were significantly different between the core infraction area (right frontal lobe, red box) and the contralateral healthy area (left frontal lobe, white box), where CBV and CBF were decreased, and MTT, TTP and Tmax were increased.

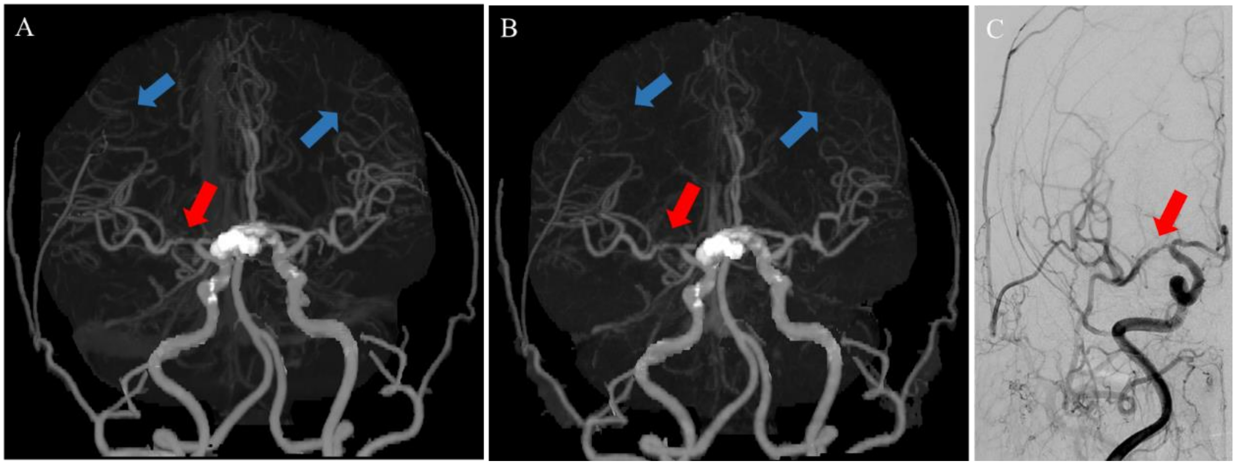

Figure 3 Maximum intensity projection of perfusion-derived cerebral CTA with artificial intelligence iterative reconstruction from Gorup A (A), and routine cerebral CTA with hybrid iterative reconstruction from Group B (B) of a 69-year-old female with severe stenosis of the right middle cerebral artery (red arrow) confirmed by digital subtraction angiography (C). When A and B are compared, Image A shows an improved intracranial artery visualization, especially for small arterial details on distal second-order branches with reduced image noise (blue arrows). The rating of the sharpness of the vascular edge, and the small vessel visibility was 5 vs. 4 and 5 vs. 4 for images A and B, respectively.

4. Discussions

In this study, one-stop dynamic whole-cerebral CTP with a 320-row scanner was performed on patients with AIS, which allows the rapid and accurate detection of acute ischemic areas. By using the advanced AIIR algorithm, perfusion-derived CTA images achieved comparable diagnostic image quality to that of routine CTA for AIS patients, while also providing enhanced small vessel visibility.

Although there is currently no reference standard for the selection of imaging type in patients with AIS, CTP is used in many stroke centers for patient selection (18). The DEFUSE 3 trial (Endovascular Therapy Following Imaging Evaluation for Ischemic Stroke 3) showed that AIS patients with a large penumbra and a small ischemic core revealed by perfusion imaging would benefit from mechanical thrombectomy outside of a 6-h therapeutic window (up to 16 h pose-onset) (19). CTA in diagnosing patients with AIS is also crucial, given that CTA helps in detecting the responsible vessels or occluded vessels. In this study, one-stop dynamic whole-brain CTP enables simultaneously CTP and CTA imaging, accelerating the clinical workflow for AIS patients. Although a fixed tube voltage (100 kVp) was used in this study, we were able to achieve a radiation dose comparable to that of previously reported CTP protocols with a fixed 80 kVp (CTDIvol: 163.2 vs 184.2 mGy) by adapting the tube current in different phases (16).

In contrast to the conventional scan protocols of performing CTA separately, the intracranial CTA images were derived from CTP at the peak arterial phase in this study. Results have shown perfusion-derived CTA with AIIR could achieve comparable diagnostic image quality to that of the routine CTA for AIS patients, thereby eliminating the need to perform an additional CTA scan which in turn reduces the need for additional radiation exposure and contrast agent.

There were several limitations in this study. First, the study population was relatively small, and a larger cohort may provide additional insights into the clinical utility of one-stop dynamic whole-cerebral CTP. Additionally, the investigation was conducted only in the routine dose setting that we believed to be most relevant in practice. Expanding this evaluation to a low-dose setting would be one of our future interests.

5. Conclusion

In conclusion, one-stop dynamic whole-cerebral CTP allows for rapid and accurate detection of ischemic core and tissues at risk. Moreover, by using the advanced artificial intelligence iterative reconstruction, the perfusion-derived CTA could achieve comparable diagnostic image quality to that of the routine cerebral CTA, thereby reducing radiation exposure and accelerating the clinical workflow for AIS patients.

6. Image/Figure Courtesy

All images are provided courtesy of The Affiliated Guangdong Second Provincial General Hospital of Jinan University, Guangzhou, China.

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