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Clinical study of colorViz fusion image vascular grading based on multi-phase CTA reconstruction in acute ischemic stroke

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Abstract

Objective This study aimed to evaluate the diagnostic value of ColorViz fused images from multi-phase computed tomography angiography (mCTA) using GE Healthcare's FastStroke software for newly diagnosed cerebral infarctions in patients with acute ischemic stroke (AIS).

Methods A total of 106 AIS patients with unilateral anterior circulation occlusion were prospectively enrolled. All patients underwent mCTA scans during the arterial peak phase, venous peak phase, and venous late phase. The vascular information from these mCTA phases was combined into a time-varying color-coded image using GE Healthcare's FastStroke software. All participants also underwent magnetic resonance diffusion-weighted imaging (MR-DWI) within three days. The diagnostic capability of the mCTA ColorViz fusion images for identifying newly diagnosed intracranial infarction was assessed using MR-DWI as the gold standard, focusing on the degree of delayed vascular perfusion and the number of visible blood vessels.

Results The mCTA ColorViz fusion images revealed ischemic changes in brain tissue, demonstrating a sensitivity of 88.7% for superficial infarctions and 48.5% for deep infarctions. Additionally, the subjective vascular grading score of the mCTA ColorViz fusion images showed a strong negative correlation with the infarct area identified by MR-DWI ($r = -0.6$, $P < 0.001$).

Conclusion The mCTA ColorViz fusion images produced by FastStroke software provide valuable diagnostic insights for newly diagnosed cerebral infarction in AIS patients. The sensitivity of these images is notably higher for superficial infarctions compared to deep ones. This technique allows for relatively accurate detection of the ischemic extent and the likelihood of infarction in the superficial regions where lesions are located.

Keywords ColorViz fusion image, Vascular grading score, Newly diagnosed infarction, Infarct area

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Introduction

Ischemic stroke is a prevalent condition characterized by high incidence, mortality, disability, and recurrence rates [1–3]. It manifests as a clinical syndrome marked by sudden local brain function deficits resulting from the interruption of cerebral blood supply due to various causes, leading to neurological dysfunction [4, 5]. A report from China on Stroke Prevention and Treatment indicated that the stroke mortality rate in 2018 was 149.49 per 100,000 people, accounting for 22.3% of the country's total mortality rate [6, 7]. Consequently, stroke has emerged as a significant contributor to premature death and disease burden, imposing a substantial economic strain on society and families. Cerebral artery occlusion is the most common cause for ischemic stroke, and thrombolytic therapy is the preferred treatment [8, 9]. Collateral circulation is a key factor influencing the extent of ischemic stroke infarction, intra-arterial treatment, and clinical prognosis [10]. Studies have demonstrated a significant correlation between perfusion changes, collateral circulation, and the progression of infarction [11]. Effective collateral circulation can extend the treatment window after a stroke and increase the brain's tolerance to ischemia and hypoxia. It also enhances the benefits of acute vascular recanalization therapy, reduces infarct volume, and improves overall prognosis [12]. Effective collateral circulation can significantly reduce the risk of stroke recurrence [13]. The "Chinese Guidelines for the Standardized Application of Cerebrovascular Disease Imaging," issued in 2019, recommend a comprehensive CT/Magnetic Resonance (MR) evaluation for patients with an unknown onset time or an onset time exceeding 6 h. This evaluation includes non-contrast CT/Magnetic Resonance Imaging (MRI), CTA/ magnetic resonance angiography (MRA), and perfusion imaging. For facilities with adequate resources, performing multi-phase CTA scans is advisable to accurately assess collateral circulation. The phrase "Time is Brain" has evolved into "Imaging is Brain." Currently, CT modalities are recommended as the first-line imaging tool for AIS due to their applicability to nearly all patients, shorter examination times compared to MR modalities, and the capability for rapid "one-stop" scanning. While conventional single-phase vascular imaging can identify the culprit vessel lesion, it lacks temporal resolution and may overlook critical hemodynamic information. Multi-mode CT angiography allows for comprehensive evaluation of vascular stenosis and plaque characteristics in the head and neck, effectively assessing the responsible vessel and providing detailed brain perfusion parameters [14]. Multi-phase mCTA is a time-resolved imaging technique that reveals more collateral circulation information, accurately predicts functional outcomes for patients, and streamlines the collateral circulation evaluation process [15, 16]. Computed tomography perfusion (CTP) involves the intravenous injection of a contrast agent followed by spiral CT scanning as the agent passes through the cerebral vessels. This method provides a direct and effective reflection of cerebral tissue perfusion and demonstrates high diagnostic sensitivity and specificity during the early stages of stroke onset [17]. However, perfusion scanning has several limitations. Its extended duration may be affected by patient movements, leading to scan failures and prolonged time in the radiology department, which can delay treatment. Additionally, perfusion scanning requires higher doses of contrast agent, increasing the associated risks. In primary hospitals and initial stroke centers, healthcare providers without specialized training may find it challenging to interpret perfusion images, and post-processing of perfusion data heavily relies on software, which can produce inconsistent parameter values affecting interpretation. To address these challenges, GE Healthcare has introduced FastStroke technology, which facilitates the packaging and post-processing of CT scan data for stroke patients. This technology can also merge multi-phase CTA images into a single set of 4D color images, referred to as ColorViz fusion images. A study [18] has demonstrated that this method intuitively displays collateral circulation status and outperforms traditional multi-phase CTA images in diagnosing distal vascular embolism, multiple embolisms, and symmetrical embolisms. Its ease of interpretation makes it particularly suitable for beginners. ColorViz fusion images can reduce the time required for vascular grading and have the potential to improve inter-rater consistency [18, 19]. Moreover, this technology can assess collateral circulation and evaluate blood flow perfusion status, showing a good correlation with DSA collateral circulation grading, which is beneficial for patients considering endovascular therapy [20].

This study examines the evolution of lesions in AIS and compares the efficacy of ColorViz fusion image vascular grading with MR-DWI review results. The use of ColorViz fusion images as an alternative to traditional multi-phase CTA and CTP imaging for assessing cerebral collateral circulation serves as an independent predictor of clinical prognosis and disease progression in ischemic stroke patients. This approach aims to streamline the evaluation process, reduce radiation exposure, shorten examination times, preserve more brain tissue, and enhance diagnostic capabilities for physicians in primary hospitals. Ultimately, it provides a solid foundation for promoting efficient and straightforward stroke examination protocols in primary hospitals and initial stroke centers.

Materials and methods

Data samples

This study included 106 patients who were admitted to the emergency department and received intravenous thrombolysis with recombinant tissue plasminogen activator (rt-PA) within 6 h of undergoing multiphase computed tomography angiography (mCTA). Additionally, magnetic resonance diffusion-weighted imaging (MR-DWI) was performed within 3 days for imaging evaluation between January 2023 and December 2023. Among the participants, 69 were male, aged 37 to 82, as detailed in Table 1.

Inclusion criteria were as follows: (1) patients diagnosed with stroke and aged ≥ 18 years; (2) stroke diagnosis was based on the Chinese Guidelines for Diagnosis and Treatment of Acute Ischemic Stroke (2023) [21]; (3) MDCT and mCTA scans were completed within 6 h of stroke onset, and MR-DWI scans were performed within 3 days, with clear imaging results; (4) MDCT excluded intracranial hemorrhage; (5) CTA demonstrated acute occlusion of the unilateral anterior cerebral artery or middle cerebral artery.

Exclusion criteria included: (1) incomplete patient information, poor cooperation, or unclear images; (2) presence of intracranial hemorrhage or subarachnoid hemorrhage; (3) posterior circulation ischemia; (4) stroke due to brain tumors, head trauma, blood disorders, etc.

AIS, acute ischemic stroke. NIHSS, National Institutes of Health Stroke Scale.

CT scanning protocol

A GE Revolution CT scanner with 256-detector rows was used for the study. Upon emergency admission, all patients underwent non-contrast enhanced CT scans and mCTA scan. plain CT scan was used to exclude cerebral hemorrhage and observe possible ischemic lesions and their scope. mCTA was performed using spiral scanning with a rotation time of 0.5 s and a pitch of 0.992:1. During the arterial phase, the cranial vertex to the aortic arch was the range of scanning. In the venous and late venous phases, only a whole-brain scan was performed; in the arterial phase, the scanning range extended from the aortic arch to the cranial vertex. The gap between the late venous phase and venous phase, as well as between the arterial and venous phases, was maintained with a delay of 8s each. Iohexol (350 mg/ml) was injected into the right median cubital vein at a flow rate of 5.0 ml/s as a contrast agent. If the patient undergoes a CTP scan, it should be performed in axial mode, with the scanning direction from the cranial base to the cranial vertex. The scan range should be 16 cm, the rotation time set to 0.5s, the slice thickness to 5 mm, the scan interval to 2.5 mm, and the total scan duration to 50s. The contrast agent administration method should be the same as that used for CTA. Thirty milliliters of normal saline were flushed at a consistent flow rate, with a total scanning time of approximately 18s. The layer thickness for reconstructing the original data was set at 0.625 mm. A multi-model adaptive iterative algorithm was utilized alongside the

Table 1 Clinical and imaging data of 106 patients with AIS

Basic information	AIS (*n* = 106)	
Gender		
Male	69 (65.1%)	
Female	37 (34.9%)	
Time to stroke onset (hours)		
< 4.5	58 (54.7%)	
4.5 ~ 6	48 (45.3%)	
Admission NIHSS score (points)		
1 ~ 4	5 (4.7%)	
5 ~ 15	37 (34.9%)	
16 ~ 20	34 (32.1%)	
21 ~ 42	30 (28.3%)	
Location of vascular lesion		
The anterior cerebral artery A1 segment/middle cerebral artery M1 segment	47 (44.3%)	
The anterior cerebral artery A2-A5 segment/middle cerebral artery M2-M5 segment	59 (55.7%)	
Vascular grading	Deep region	Superficial region
0	5 (4.7%)	0 (0.0%)
1	4 (3.8%)	12 (11.3%)
2	13 (12.3%)	10 (9.4%)
3	28 (26.4%)	27 (25.5%)
4	3 (2.8%)	34 (32.1%)
5	0 (0.0%)	8 (7.5%)
Negative	53 (50.0%)	15 (14.2%)

Table 2 FastStroke collateral circulation scoring criteria [22]

Collateral circulation score (points)	FastStroke findings
5	Normal or increased vessels number in ischemic area, with all vessels in the ischemic area colored red
4	Normal or slightly decreased (≥ 90%) vessels number in ischemic area, with red and green vessels present in the ischemic area, but mostly red vessels
3	Normal or slightly decreased (≥ 90%) vessels number in ischemic area, with red, green, and blue vessels present in the ischemic area; or a decrease (50%~90%) in the vessels number in ischemic area, with vessels colored red and/or green
2	A decrease (50%~90%) in the vessels number in ischemic area, with red, green, and blue vessels present in the ischemic area
1	A significant decrease (< 50%) in the vessels number in ischemic area, with vessels colored red, green, and blue present in the ischemic area
0 points	No visible vessels in the ischemic area on the affected side

Table 3 Comparison of detection of AIS diagnosed by DWI and ColorViz Fusion images in superficial areas

Detection methods		DWI	
		Positive	Negative
ColorViz Fusion images	Positive	86	5
	Negative	11	4

DWI, diffusion-weighted imaging

patient's scan, effectively reducing radiation dose while maintaining image quality. Magnetic resonance imaging was performed using a Siemens MAGNETOM Vida 3.0T MR scanner with a matching head phased array coil. A single-shot spin-echo imaging sequence was employed, featuring b-values of 0 and 1,000 s/mm², a TE of 105 ms, a TR of 3,100 to 4,000 ms, a layer spacing of 1.8 mm, a layer thickness of 6.0 mm, a matrix of 160 × 160, a field of view of 260 mm × 220 mm, and a scanning time of 48 to 50s. The scanning range extended from the base of the skull to the cranial vertex.

Image analysis

The reconstructed images from three-phase vascular scans were transmitted to a GE 4.7 workstation and processed using the FastStroke technique to generate ColorViz fusion images. An adaptive threshold technique was employed to assign colors to blood vessels based on the timing and degree of contrast agent enhancement, as well as each patient's adaptive threshold. Red indicated arterial phase enhancement, green represented venous phase enhancement, and blue signified late venous phase enhancement. The ColorViz fusion image was reconstructed using maximum intensity projection (MIP) along the orbitomeatal-basal line. The grading criteria included the 6-point collateral circulation score scale, along with the colors and quantities of blood vessels [22], as detailed in Table 2.

Patients were classified into two groups based on the location of the lesion: the deep group and the superficial group. This classification was determined by the supply of perforating and cortical arteries. The deep group included the basal ganglia, internal capsule, thalamus, corona radiata, and corpus callosum, while the superficial group encompassed the frontal lobe, parietal lobe, temporal lobe, occipital lobe, insula, and external capsule. The diffusion-weighted imaging (DWI) sequence revealed high-signal infarction lesions with restricted diffusion, and the apparent diffusion coefficient (ADC) sequence displayed low-signal changes. Lesions were classified as new infarctions if there was no history of stroke within the preceding month. Patients with new infarcts were selected based on lesion size, with the maximum area of the infarct measured using the About Neusoft PACS Version 5.5 workstation employing multi-point measurement.

Two senior physicians, blinded to the CTA images, independently assessed the blood vessels in the deep and superficial regions of the ColorViz fusion image, assigning a vascular grading score and identifying cases of new infarction lesions on DWI. In cases of disagreement regarding the lesion's location in the ColorViz fusion image, the more favorable results or lower vascular grading scores were selected. The location and area of the infarction in the DWI image were then compared and included in the statistical analysis.

Statistical analysis

The sensitivity and specificity of MR-DWI and ColorViz fusion images were analyzed separately for the deep and superficial groups. Additionally, the maximum cross-sectional area of new infarcts was compared with vessel grading. Pearson's correlation coefficient was calculated for all patients, using a threshold of $P < 0.05$ for statistical significance. A correlation value of $|r| > 0.8$ indicated a strong correlation, while $0.6 < |r| \leq 0.8$ indicated a moderate correlation, $0.4 < |r| \leq 0.6$ indicated a weak correlation, and $|r| \leq 0.4$ indicated a negligible correlation.

Results

AIS detected in superficial areas using ColorViz fusion images

Among the 106 patients in the superficial group, 86 cases were diagnosed as positive for both vascular grading and DWI, while 11 DWI-positive patients had negative vascular grading, and 5 were positive for vascular grading but negative for DWI (Table 3). Using MR-DWI as the gold standard for the diagnosis of AIS, we found that the sensitivity of using ColorViz fusion images in the superficial areas was 88.7%, specificity was 44.4%, accuracy was 84.9%, positive predictive value was 94.5%, and negative predictive value was 26.7%.

AIS detected in deep areas using ColorViz fusion images

In the deep group, 47 cases were diagnosed as positive for both vascular grading and DWI, while 50 DWI-positive patients had negative vascular grading. Additionally, 6 cases were diagnosed as positive for vascular grading but negative for DWI (Table 4). Using MR-DWI as the gold standard for the diagnosis of AIS, we found that the sensitivity of using ColorViz fusion images in the deep regions for the diagnosis of AIS was 48.5%, with a specificity of 33.3%, accuracy of 47.2%, positive predictive value of 88.68%, and negative predictive value of 5.7%.

Table 4 Comparison of detection of AIS diagnosed by DWI and ColorViz fusion images in deep areas

Detection methods		DWI	
		Positive	Negative
ColorViz Fusion images	Positive	47	6
	Negative	50	3

DWI, diffusion-weighted imaging

Table 5 The correlation of ColorViz fusion images vascular grading with AIS area

ColorViz fusion images vascular grading	Area of cerebral infarction	
	r value	*P* value
Superficial areas	-0.7	< 0.001
Deep areas	-0.6	< 0.001

Correlation of ColorViz fusion images vascular grading with cerebral infarct area

The results of the correlation analysis between cerebral infarct area and ColorViz fusion images vascular grading are shown in Table 5. The r value of the correlation between ColorViz fusion images vascular grading and cerebral infarct area in superficial areas was − 0.7 ($P < 0.01$). The r value of correlation between ColorViz fusion images vascular grading and cerebral infarction area in deep area was − 0.6 ($P < 0.01$).

ROC curve analysis of DWI-positive diagnosis of superficial area cerebral infarction area

The ROC curve for DWI-positive diagnosis of superficial area cerebral infarction area in this study is shown in Fig. 1. The analysis showed that the area under the curve (AUC) for DWI-positive diagnosis of cerebral infarction area in superficial area was 0.98 ($P < 0.001$), the sensitivity of the diagnosis was 100%, the specificity was 96.5%.

Discussion

The preferred treatment for AIS is thrombolysis. Numerous studies have demonstrated that the status of collateral circulation in AIS patients is associated with the effectiveness of intravenous thrombolysis and the prognosis of endovascular treatment, serving as a predictive indicator for ischemic stroke outcomes [23–25]. Robust collateral circulation is strongly correlated with a reduced risk of hemorrhagic transformation, a higher success rate of endovascular therapy, and a favorable clinical prognosis [26]. In cases of insufficient collateral circulation, the extent of neural damage from cerebral infarction tends to be more severe, resulting in a poorer prognosis [27]. Cerebrovascular collateral circulation can be classified into three levels [28]. Level 1: Anterior and posterior communicating arteries of the Circle of Willis. Level 2: Collateral branches of the intracranial meningeal artery, anatomical shunts from extracranial vessels, and collateral pathways of intracranial vessels. Level 3: Neovascular capillaries. In this study, five patients exhibited a vessel grading score of 5, all of whom had intact Circle of Willis structures in their internal carotid arteries. However, due to congenital variations, some patients presented with incomplete Circle of Willis formations, resulting in a longer time window for the effectiveness of Level 3 collateral circulation, which limited its benefits for AIS patients. Consequently, Level 2 collateral vessels have a more significant impact on AIS outcomes. mCTA represents a novel imaging technology that not only reveals the filling status of blood vessels but also allows for the assessment of delays in intracranial meningeal vessels. This technology provides a comprehensive and accurate evaluation of the collateral circulation status in AIS patients [29, 30].

The ColorViz fusion image, created using FastStroke software, effectively integrates color indicators with the advantages of mCTA. This method provides a more intuitive visualization of collateral vessels, allowing the scorer to assess a single sequence image [20, 27, 31]. Additionally, traditional mCTA evaluations of collateral circulation typically take about one minute, whereas the ColorViz fusion image assessment requires only a few seconds. This image offers a more three-dimensional and intuitive representation, making it particularly valuable for inexperienced physicians [18]. Previous studies have demonstrated that the score of the meningeal collateral circulation (rLMC) is associated with the formation and prognosis of collateral circulation [32]. A favorable rLMC is crucial for maintaining blood supply to the infarcted area, preventing the expansion of the infarct, and promoting survival in the ischemic penumbra [33, 34]. The occurrence of acute cerebrovascular embolism, along with the extent of brain tissue damage, is directly related to the degree of meningeal artery opening as a secondary collateral vessel. This relationship highlights the significance of vascular accidents in cerebral infarction for

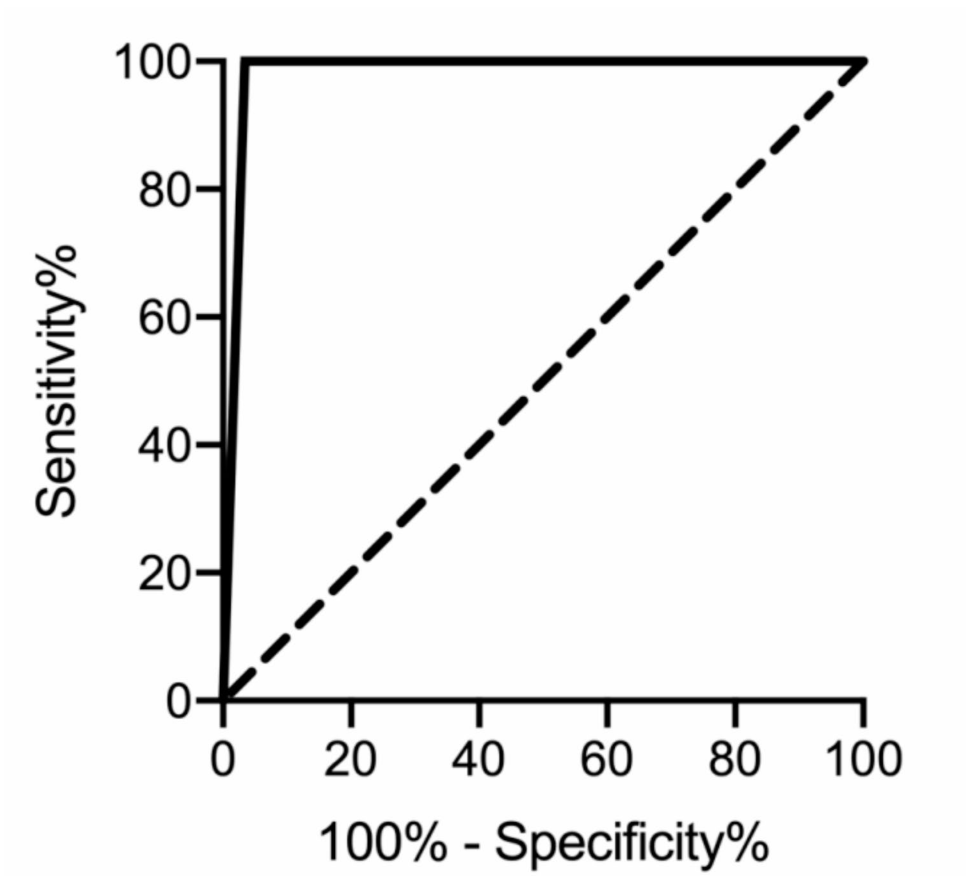

Fig. 1 ROC curve analysis of DWI-positive diagnosis of superficial area cerebral infarction area. The AUC value was 0.98, indicating that the ColorViz image is more efficient in diagnosing positive lesions in the superficial area

patient prognosis. Furthermore, the ColorViz fusion image collateral circulation score demonstrates strong predictive value for favorable functional outcomes in patients [35]. The study's findings revealed a significant negative correlation between superficial vascular grading and the area of cerebral infarction, consistent with prior research [32].

In the patient illustrated in this article, the right middle cerebral artery was occluded. Although no large core infarction was evident on computed tomography perfusion (CTP) (Fig. 2), the ColorViz fusion imaging indicated a cortical vascular grading of grade 2, suggesting a high likelihood of significant infarction in this region. Review results corroborated this assessment, showing that the extent of infarction aligned with the grade 2 vascular grading. This further confirms that the collateral vessel information obtained from the ColorViz fusion imaging is accurate and valuable for analyzing perfusion status and predicting patient prognosis. Thus, utilizing ColorViz fusion imaging for early diagnosis can inform clinical treatment and prognosis [36–38].

In our study, the sensitivity for diagnosing cerebral infarction in the superficial group was 88.7%. However, the sensitivity and specificity of the ColorViz fusion imaging for identifying infarction lesions in the deep area were significantly lower, at 48.5% and 33.3%, respectively. This disparity may be attributed to the proximity of the superficial area to more abundant meningeal arteries, which better display collateral vessels, whereas the deep area relies on smaller, sparser perforating arteries. Consequently, the ColorViz fusion imaging demonstrated higher sensitivity for detecting superficial lesions compared to deep ones. The specificity for the superficial and deep groups was 44.4% and 33.3%, respectively, likely due to diagnosing physicians misinterpreting green and/or blue vessels, while terminal branch arteries near the brain surface were often overlooked due to interference from the skull base [39]. Some scholars suggest that mCTA serves as a simplified CT perfusion method for evaluating collateral circulation and could be implemented in primary hospitals and stroke prevention centers [40].

In this study, the included patients all received only rt-PA treatment, primarily to standardize the initial conditions and provide a more objective assessment of the predictive value of ColorViz fusion images for stroke risk and severity. This offers imaging information for

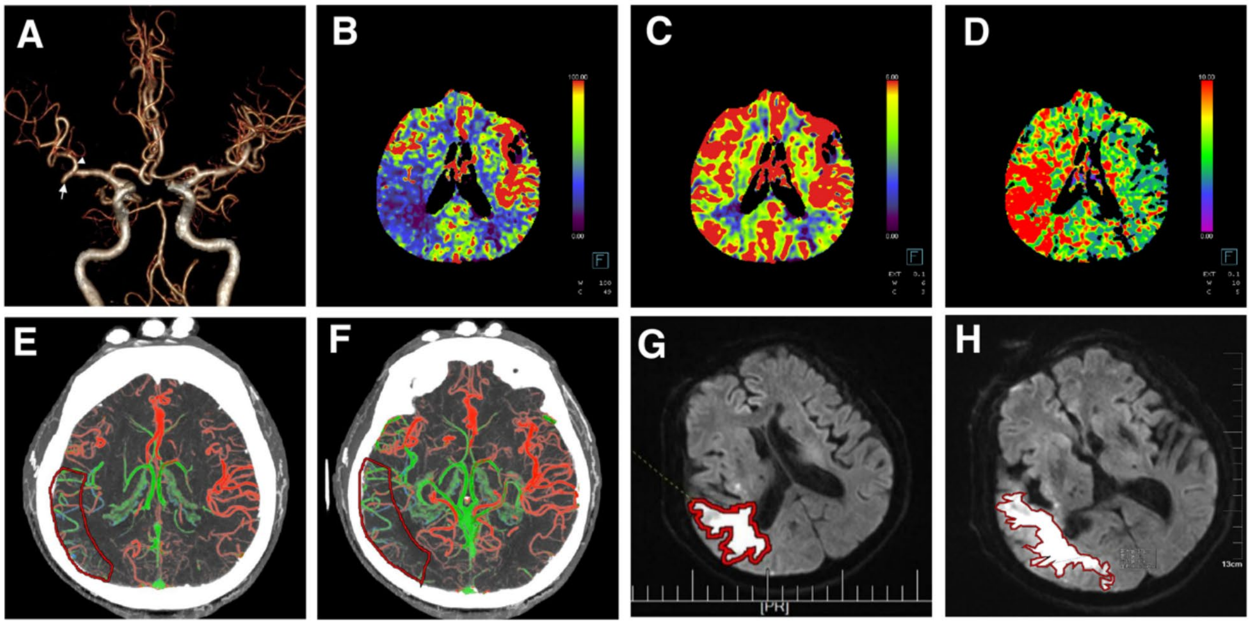

Fig. 2 Illustration of a patient with acute ischemic stroke. Multi-mode vascular findings on CT in patients with AIS. Panel A displays the intracranial CTA, indicating occlusion of the MCA supplying the parietal lobe (indicated by the white arrow). Panels B-D present CTP images (CBF, CBV, TTP) at horizontal portion of lateral ventricle, demonstrating reduced perfusion in the MCA territory, which suggests a transition to stage IIa before infarction. The center is exhibiting a small number of core infarct areas, with the main lesion's extent largely correlating with the blood supply range of the frontoparietal artery. Panels E-F show ColorViz fused images of the right middle cerebral artery (MCA) supplying the frontal lobe. Panels E is a horizontal image of the flat lateral ventricle, while panel F depicts a horizontal image of the flat basal ganglia. Based on the arterial blood supply area, the responsible frontoparietal artery's supply zone has been manually outlined on the ColorViz fused images. The vessels within the orbitofrontal artery show no significant reduction in caliber, with a few green vessels visible in the image. According to the 6-point collateral circulation grading system, these vessels are classified as grade 4. In contrast, the MCA supplying the parietal lobe exhibits reduced vessel caliber and the presence of green and blue vessels, corresponding to a collateral circulation grade of 2. Panels G and H present DWI images obtained two days after onset; panel G shows the image at the level of the flat lateral ventricle, while panel H shows the image at the level of the flat basal ganglia. These images reveal large infarcts in the superficial temporal-parietal lobe (supplied by the MCA), with a maximum infarct area of 1297 mm^2. The infarct site is concentrated within the blood supply range of the frontoparietal artery, which has a vascular grade of 2. No new infarct lesions were observed in the blood supply range of the orbitofrontal artery, which maintains a vascular grade of 4

patients who are contraindicated for or refuse endovascular treatment for various reasons. In the future, we will compare CTP with different treatment regimens based on an increasing sample size, and we will also enhance comparisons within the endovascular treatment group. Later, we plan to collaborate with Shanghai United Imaging Healthcare Co., Ltd. to integrate intracranial artery blood supply zone functionality into their United Imaging AI workstation. This will allow for a comparison of the color and quantity of vessels between the affected and unaffected sides in patients with AIS, enabling rapid assessment of collateral circulation according to the rapid stroke collateral circulation scoring criteria [41]. This approach will provide more diagnostic information for clinical decision-making in a short time frame.

Conclusion

The mCTA ColorViz fusion image generated using Fast-Stroke software demonstrates significant value in diagnosing new cerebral infarction lesions in AIS patients. Our findings indicate that the sensitivity of the mCTA ColorViz fusion image is higher in superficial areas compared to deep areas. Furthermore, this approach provides collateral vessel imaging information for patients who are unable to undergo CTP scanning or who cannot cooperate with the procedure, facilitating rapid diagnosis and precise treatment.

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Author contributions
All the authors worked on conception and methodology, wrote the main manuscript text, and prepared figures. All authors reviewed the manuscript.

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Data availability
The data used or analyzed during the current study and machine learning model are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The Institutional Review Board of First Affiliated Hospital of China Medical University, Liaoning, China, approved this study (Approval No. 2022-CMU/CN/45 – 02). An informed consent to participate was obtained from all of the participants of this study.

Consent for publication
An informed consent to publish this data was obtained from all of the participants of this study.

Competing interests
The authors declare no competing interests.

Clinical trial number
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