

Thrombus Length Evaluation on Multiphase CT Angiography in Acute Ischemic Stroke Patients

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Abstract

Background: In acute ischemic stroke (AIS) patients with proximal middle cerebral artery (MCA) occlusion, estimation of the thrombus length can be helpful for pre-procedural planning of the endovascular thrombectomy.

Objectives: To evaluate the thrombus length measurement on multiphase computed tomography angiography (mCTA) compared to the reference standard cerebral digital subtraction angiography (DSA).

Methods: Forty-five AIS patients with acute occlusion of proximal MCA underwent both mCTA and DSA were retrospectively reviewed. Thrombus length was measured on the two imaging planes of mCTA, the coronal plane and the plane parallel to arterial course, and on the anteroposterior view of DSA. We evaluated overall agreement between the measurement on the mCTA and DSA, subgroup assessment according to different thrombus location and different thrombus length, and interobserver agreement.

Results: There was overall good agreement between the measurement on DSA and both planes of mCTA. There was substantial agreement for the different thrombus location (M1, M2 and M1-M2) between mCTA and DSA, except for moderate agreement of the M1-M2 thrombus on the mCTA coronal plane. There was fair agreement across three different thrombus length (<10 mm, 10–15 mm, and >15 mm) between mCTA and DSA, except for slight agreement for the 10–15 mm thrombus on the mCTA coronal plane. The inter-observer agreement was excellent. There was no significant association between the thrombus length and the successful recanalization.

Conclusion: Thrombus length measurement on mCTA is applicable and can be practically useful in the acute stroke imaging for patient selection to endovascular thrombectomy.

Keywords: acute ischemic stroke, MCA occlusion, thrombus length, multiphase CTA (J Thai Stroke Soc. 2023;22(1): 21–31)

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การประเมินความยาวของลิ่มเลือดอุดตันในผู้ป่วยสมองขาดเลือด เฉียบพลันด้วย Multiphase CT Angiography

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บทคัดย่อ

บทนำ การประเมินความยาวของลิ่มเลือดอุดตันในผู้ป่วยสมองขาดเลือดเฉียบพลันที่มีการอุดตันของหลอดเลือดแดงมิดเดิลซีรีบรัสส่วนต้น สามารถช่วยในการวางแผนการรักษาด้วยการเปิดหลอดเลือดอุดตันผ่านสายสวนหลอดเลือด

วัตถุประสงค์ เพื่อประเมินการวัดความยาวของลิ่มเลือดอุดตันด้วย multiphase computed tomography angiography (mCTA) เปรียบเทียบกับ digital subtraction angiography (DSA) ซึ่งเป็นวิธีวัดประเมินความยาวของลิ่มเลือดที่เป็นมาตรฐาน

วิธีการวิจัย ทำการศึกษาแบบเก็บข้อมูลย้อนหลังในผู้ป่วยสมองขาดเลือดเฉียบพลันที่มีการอุดตันของหลอดเลือดแดงมิดเดิลซีรีบรัสส่วนต้น ซึ่งได้รับการตรวจประเมินด้วย mCTA และ DSA จำนวน 45 ราย โดยประเมินวัดความยาวของลิ่มเลือดในภาพสองระนาบของ mCTA ได้แก่ระนาบหน้าหลัง และระนาบที่ขนานไปกับหลอดเลือด และประเมินวัดความยาวของลิ่มเลือดในภาพระนาบหน้าหลังของ DSA โดยประเมินความเห็นพ้องของค่าที่วัดได้จากทั้งสองวิธี ทั้งแบบโดยรวมและแบบจัดกลุ่มย่อยตามความยาวและตำแหน่งของลิ่มเลือด และประเมินความเชื่อมั่นระหว่างผู้ประเมิน

ผลการศึกษา เมื่อเปรียบเทียบการประเมินวัดความยาวของลิ่มเลือดแบบโดยรวมพบมีความเห็นพ้องที่ต่ำระหว่าง mCTA และ DSA ในทั้งสองระนาบการวัดของ mCTA ในการประเมินแบบจัดกลุ่มย่อยตามความยาวของลิ่มเลือด (<10 มม, 10-15 มม, >15 มม) พบมีความสอดคล้องระดับค่อนข้างดี ยกเว้นพบมีความสอดคล้องปานกลางของลิ่มเลือดที่มีความยาว 10-15 มม จากการวัดด้วย mCTA ในระนาบหน้าหลัง ในการประเมินแบบจัดกลุ่มย่อยตามตำแหน่งของลิ่มเลือด (M1, M1-M2, M2) พบมีความสอดคล้องระดับปานกลาง ยกเว้นพบมีความสอดคล้องพอใช้ของลิ่มเลือดในตำแหน่ง M1-M2 จากการวัดด้วย mCTA ในระนาบหน้าหลัง ส่วนผลประเมินความเชื่อมั่นระหว่างผู้ประเมินอยู่ในระดับดีเยี่ยม และไม่พบมีความสัมพันธ์ระหว่างความยาวของลิ่มเลือดและความสำเร็จของการรักษาเพื่อเปิดหลอดเลือดอุดตัน

สรุป mCTA สามารถนำมาใช้ประเมินวัดความยาวของลิ่มเลือดอุดตันและเป็นวิธีที่เป็นประโยชน์ในการประเมินทางรังสีวิทยาในผู้ป่วยสมองขาดเลือดเฉียบพลันเพื่อคัดเลือกผู้ป่วยไปสู่การรักษาด้วยการเปิดหลอดเลือดอุดตันผ่านสายสวนหลอดเลือด

คำสำคัญ: ผู้ป่วยสมองขาดเลือดเฉียบพลัน, การอุดตันของหลอดเลือดแดงมิดเดิลซีรีบรัส, ความยาวของลิ่มเลือด, multiphase CTA (J Thai Stroke Soc. 2022;23(1):21-31)

Introduction

Endovascular thrombectomy (EVT) has become the standard treatment of acute ischemic stroke (AIS) patients with acute large arterial occlusion in the anterior circulation since 2015.¹ In the patients who meet criteria of EVT, non-invasive vascular study should be done before the catheter angiography in order to confirm the arterial occlusion, thrombus localization and procedure planning.²

In AIS patients with acute large arterial occlusion, thrombus imaging characteristics and locations have been shown to have an impact on success of recanalization. Occluded vessels with thrombus length exceeding 8 mm are most likely to fail recanalization by intravenous recombinant tissue plasminogen activator.³ Thrombus length can be useful in qualifying patients for EVT and prediction of infarct size and risk of acute parenchymal hemorrhage.^{4, 5} Shorter thrombus length and more distal site of occlusion are associated with better functional outcome and faster endovascular procedure.⁴ Also, thrombus length measurement can be helpful for the interventionist to select the proper size and length of the stent retriever before initiate the thrombectomy procedure.⁶

Various non-invasive imaging modalities have been used for thrombus evaluation, including non-enhanced computed tomography (CT), susceptibility weighted imaging magnetic resonance imaging (SWI-MRI), CT angiography and magnetic resonance (MR) angiography. CT angiography is widely used for evaluating acute large arterial occlusion in the AIS patients. Multiphase CT angiography (mCTA) has been increasingly performed according to its ability to provide information of pial arterial collateral in the time resolved manner that help overcome

the delayed pial arterial contrast filling in the patients with proximal arterial occlusion.⁷ Recent studies have demonstrated that mCTA improves the detection of arterial occlusion in anterior circulation as compared with single-phase CTA, especially for the less experienced physicians.⁸⁻¹⁰

The progressive retrograde pial arterial filling of the contrast media on delayed phases of mCTA can provide visualization of the distal end of the intraluminal thrombus that help in thrombus detection and estimation of the length of the occluded site. Then, we aimed to assess the agreement of the thrombus length measurement on mCTA in patients with proximal middle cerebral artery (MCA) occlusion compared to the reference standard cerebral digital subtraction angiography (DSA).

Materials and methods

Study design and patients

The study was approved by the Institutional Review Board of the Faculty of Medicine, Chulalongkorn University, Bangkok, Thailand (certificate of approval no. 550/2020). The formal consent was waived according to retrospective study and the analysis used anonymous clinical data.

Inclusion criteria for the study were as follows: (1) patients with AIS underwent acute stroke imaging protocol at the emergency department of King Chulalongkorn Memorial Hospital between February 2018 and February 2020, and (2) patient who had blockade of proximal portion (M1 segment) of MCA or its first order branch (M2 segment) and underwent EVT afterward. Patient who had poor image quality, different occluded sites between CTA and DSA indicating clot migration, or whom with distal

occluded site cannot be outlined on any phase of mCTA or DSA were excluded.

Patients' data were recorded for each case including age, gender, location of the thrombus and type of the EVT procedure. Outcome of recanalization was recorded as the TICI score as described in the official radiology report of DSA. Successful recanalization was defined by TICI 2b or 3.¹¹

Imaging Protocol

The acute stroke imaging was performed on the 256-slice multidetector CT scanner (Revolution CT, GE Healthcare, Milwaukee, USA) installed at the emergency department. The acute stroke imaging protocol includes unenhanced CT brain, CT angiography of the brain and neck, and CT brain perfusion. mCTA was performed as the routine protocol of CT angiography with the following parameters; helical scan, 120 kVp, 400–650 mA, detector coverage 160 mm, pitch 0.992:1, coverage speed 158.75 mm/s, rotation time 0.5 s.

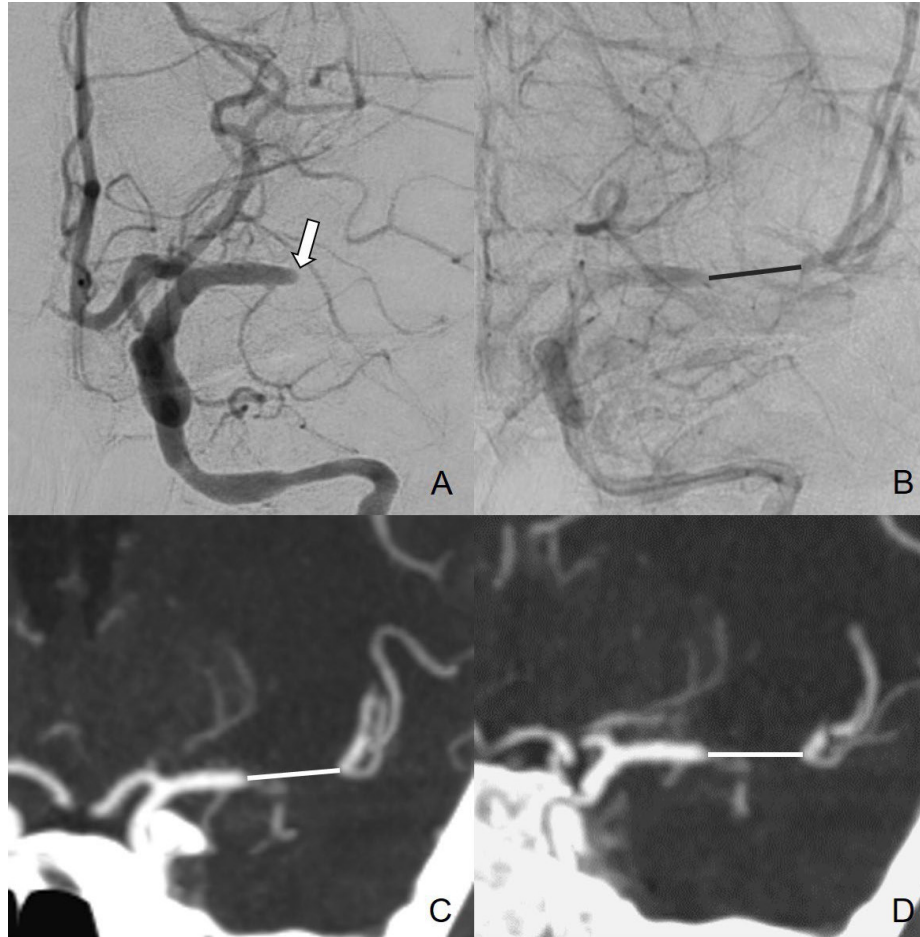
CT angiography was performed with the first dose of iodinated contrast (65 ml of Iopamidol, 5 ml/s) before the second dose for CT brain perfusion. Three phases of mCTA were acquired each 8 seconds apart, and then reconstructed into axial 0.625-mm thickness and axial maximal intensity (MIP) 8-mm thickness and then sent to the picture archiving and communication system (PACS).

Imaging Analysis

For the thrombus length measurement on mCTA, first, only one phase of mCTA that gave the best delineation of both proximal and distal sites of the occluded thrombus was selected after reviewing all the three phases. Then, the MIP

images were manually reconstructed from the axial 0.625-mm images of the selected phase, using routine image viewing software (Synapse, Fuji Film). Thrombus length was measured on the orthogonal coronal plane and the parallel plane which is the manually adjusted plane that most parallel to the arterial course. Thickness of the reconstructed MIP images was set for the best visualization of both proximal and distal sites of the occluded thrombus. The measurement of the thrombus length was done by drawing a linear line between the most demarcated proximal filling of blocked MCA and the most demarcated distal filling of the closest retrograde collateral vessel. For the DSA, the estimation of thrombus length was measured by drawing a linear line in the anteroposterior image projection, between the most demarcated proximal filling of blocked MCA and the most demarcated distal filling of the closest retrograde collateral vessel (**Figure 1**).

Figure 1. Early arterial phase DSA (A) of a 40-year-old male patient shows occlusion of proximal M1 segment of left MCA (white arrow). The linear line drawing for the thrombus measurement (thin black line) was done on the delayed arterial phase DSA (B) that well demonstrates both proximal and distal occluded sites. Thrombus measurement (thin white line) on the first phase of mCTA was made on the coronal (C) and parallel (D) MIP images.



A 12-year-experienced board certified diagnostic neuroradiologist (SP) and a second-year radiology resident (MC) independently measured the thrombus length on the two mentioned mCTA imaging planes. Thrombus length measurement on the DSA was done separately from the measurement on mCTA by the diagnostic neuroradiologist (SP) and the interventional neuroradiologist (KL) in consensus.

Statistical analysis

Statistical analysis was performed using SPSS software version 25.0 (IBM Corporation,

Armonk, New York). The Shapiro-Wilk test was used to test the normality of the continuous variables. Continuous data were expressed as the means $\pm$ standard deviation (SD) and categorical data were described as counts and percentages. Overall agreement of the thrombus measurement on mCTA and DSA was assessed with Bland-Altman plots. Intra-class correlation coefficient (ICC) was used to evaluate the absolute agreement of thrombus length between mCTA and DSA, based on subgrouping into different thrombus length and different thrombus location, and also the inter-observer agreement, using two-way

mixed-effects model (3,k). The ICC values were interpreted as follows, <0.20 slight agreement, 0.21–0.40 fair agreement, 0.41–0.60 moderate agreement, 0.61–0.80 substantial agreement and 0.81–1.0 almost perfect agreement.¹²

Independent *t* test was used to compare two groups of successful and unsuccessful recanalization. Then, logistic regression analysis with odds ratio was used to evaluate the association between thrombus length and successful recanalization after thrombectomy. P-value <0.05 was considered statistically significant.

Result

There were 83 patients met the inclusion criteria. Thirty-eight patients were excluded; 2 cases of clot migration with more distal thrombus location on the DSA compared to

mCTA, 35 cases those the distal occluded site cannot be outlined on the DSA but well seen on the mCTA, and one case whom the distal occluded site cannot be outlined on both DSA and mCTA. Then, there were 45 patients included for imaging analysis (**Figure 2**). Twenty-two were men (48.9%) and 23 were women (51.1%). The mean ($\pm$ SD) age was 60.2 ($\pm$ 15.2) years and age ranged from 25 to 84 years. Intravenous thrombolysis was given in 31 patients (68.9%). Successful recanalization (TICI 2b or 3) was achieved in 40 patients (88.9%). The EVT procedures were aspiration in 28 (62.2%) and stent retriever with aspiration in 17 (37.8%) patients. The patients were grouped according to different thrombus location; M1, M2 and both M1 and M2 (M1–M2) and different thrombus length; <10 mm, 10–15 mm, and >15 mm. The number of patients in each group was shown in (**Table 1**).

Figure 2. Patients selection flow chart.

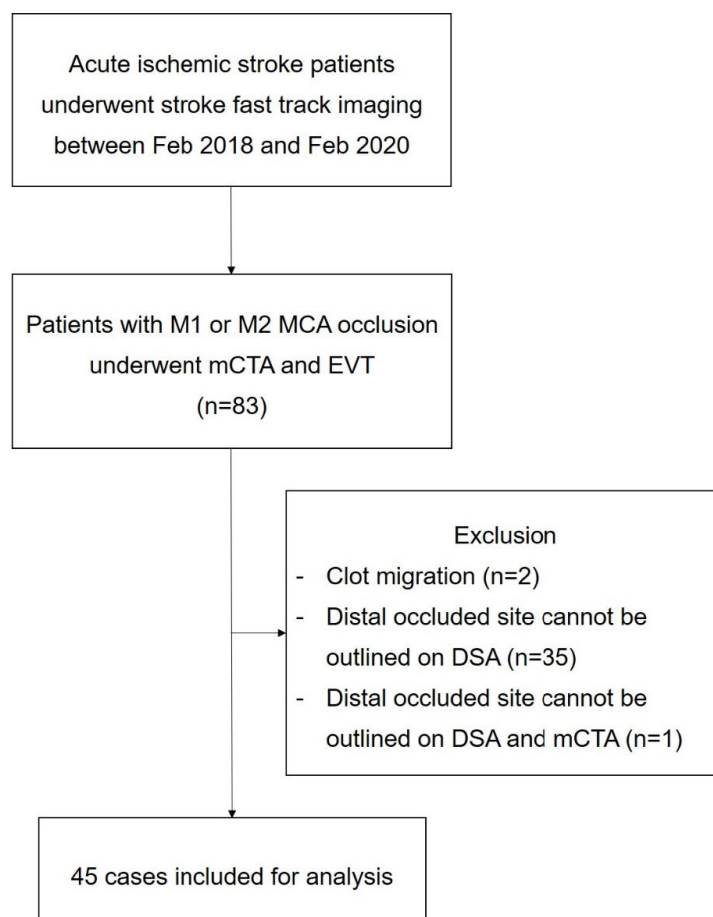


Table 1. Intraclass correlation coefficient (ICC) for agreement analysis between thrombus length measurement on both planes of mCTA compared to the DSA according to different thrombus location and different thrombus length, and interobserver agreement.

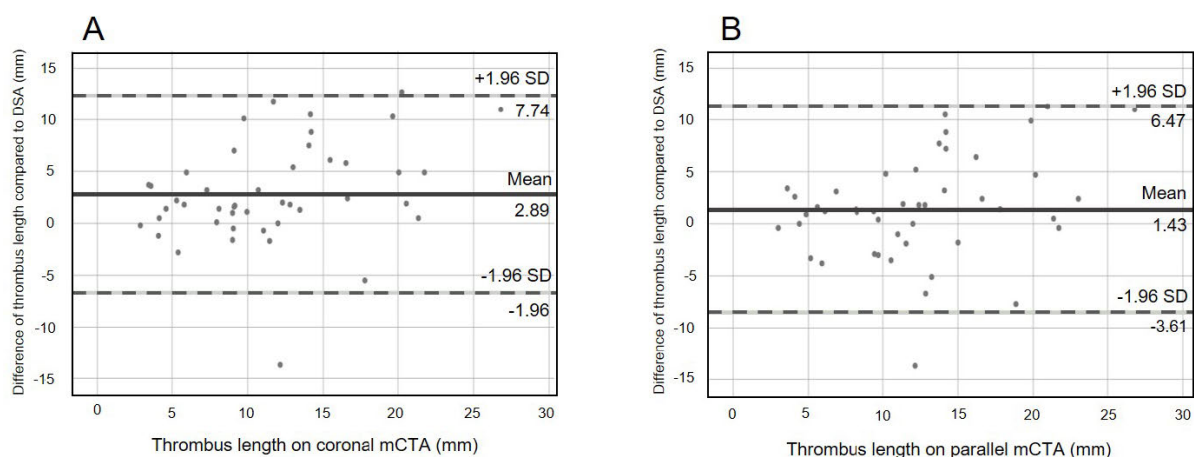
Parameters	Number of patients (%)	ICC	
		Coronal mCTA	Parallel mCTA
Thrombus location: M1	11 (24.4%)	0.792	0.699
M2	9 (20.0%)	0.636	0.619
M1-M2	25 (55.6%)	0.564	0.658
Thrombus length: <10 mm	19 (42.2%)	0.272	0.340
10–15 mm	11 (24.4%)	0.121	0.207
>15 mm	15 (33.3%)	0.305	0.329
Inter-observer agreement	45 (100%)	0.990	0.981

ICC, intraclass correlation coefficient; mCTA, multiphase computed tomography angiography.

Thrombus length was normally distributed ($p=0.72$). Mean thrombus length was 13.1 (± 7.0) mm. The Bland–Altman plot of mCTA thrombus length on both measuring planes compared

to the measurement on DSA was shown in (**Figure 3**). There was good agreement between DSA measurement and mCTA measurement on both coronal and parallel planes.

Figure 3. Bland–Altman plot for thrombus length measurement on mCTA coronal plane (A) and parallel plane (B) compared to the reference standard DSA.



Detail agreement analysis between thrombus length measured on DSA and both planes of mCTA according to different thrombus location and different thrombus length and interobserver agreement were shown in (Table 1). Regarding different thrombus location, there was substantial agreement between mCTA and DSA measurement for all thrombus location in both mCTA measuring planes, except for the M1–M2 thrombus measured on the mCTA coronal plane which shows moderate agreement. Regarding different thrombus length, there was fair agreement between DSA and mCTA measurement on both mCTA measuring planes across the three groups, except for slight agreement of the 10–15 mm. thrombus measured on mCTA coronal plane. There was almost perfect agreement for the mCTA thrombus measurement between the two reviewers in both mCTA coronal plane and parallel plane.

Successful recanalization was achieved in 40 cases (88.9%). The mean ($\pm$ SD) thrombus length of the patients with successful recanalization (12.7 ± 7.1 mm) tends to be slightly shorter than the patients with unsuccessful recanalization (16.2 ± 5.4 mm), but there is no statistical significance ($t(43) = -1.08$, p value 0.29). Logistic regression analysis showed no significant association between the thrombus length and the successful recanalization after EVT (odds ratio = 0.93, p value 0.29).

Discussion

Our study demonstrates overall good agreement of the thrombus length measured on the mCTA compared to the reference standard DSA, in keeping with the study by Polito et al.⁶ There was almost perfect interobserver agreement between the radiology resident and

experienced neuroradiologist. Thus, there is no difference of the mCTA thrombus length measurement between the skilled radiologist and the less experienced imaging interpreter. These also support the usefulness of the mCTA along with improving diagnostic accuracy of intracranial arterial occlusion detection in the less experienced readers demonstrated by previous studies.^{8, 10}

From the results of the agreement analysis according to the different thrombus location, we may suggest that for mCTA measurement of the thrombus solely occluding M1 or M2 segment on the orthogonal reconstructed coronal plane could be fairly comparable to the DSA measurement. But for the thrombus occluding both M1 and M2 segments (M1–M2), the imaging plane reconstructed parallel to the arterial course may offer more accurate measurement.

Among our 83 AIS patients met the initial inclusion criteria, the distal end of the thrombus cannot be outlined on the DSA in 36 patients but can be well delineated on the mCTA in nearly all except one patient. In those excluded patients, we postulated that good collateral with slow retrograde pial arterial blood flow in the occluded territory, together with smaller amount of the contrast media used in each intra-arterial injection and shorter delay time of the DSA compared to mCTA may cause limited delineation of the distal thrombus on the DSA.^{13–14} Therefore, the mCTA may provide the pre-procedural evaluation of the thrombus length in this condition and may allow proper device selection before initiation of the endovascular treatment.

We found no significant association between the length of the thrombus and the efficacy of the mechanical recanalization, in ac-

cordance with the results from previous studies demonstrated that the thrombus length had no clear effect on the successful recanalization of EVT in the AIS patients with MCA occlusion.^{15–17} On the other hand, some studies found correlation of the thrombus length or thrombus volume with the recanalization rate, in which the successful recanalization diminished with increasing thrombus size.^{18–20} However, those previous works included large arterial occlusions in both anterior and posterior circulations which could have influenced the different results.

Pre-procedural estimation of the thrombus length has an impact on outcome of mechanical thrombectomy. Approximation of the thrombus length can be helpful for the interventional neuroradiologist to select the proper size of the stent retriever in order to achieve successful recanalization.⁶ Moreover, Belachew et al. found that the lower thrombus length/stent retriever length ratios were associated with successful recanalization, while the high ratios may increase the risk of unsuccessful recanalization and embolization in new territories. Additionally, the thrombus size or stent retriever size alone may not directly influence the recanalization success.²¹

Compared to single phase CTA, mCTA not only provides more accurate arterial collateral status, the mCTA can also help in thrombus detection and pre-procedural evaluation of the thrombus length that may allow prompt management decision, better procedure planning and may contribute to improving patient's clinical outcome. Special software is not required for mCTA image post processing and the mCTA interpretation is simple and straightforward.^{7–8, 10} And, our study also supports the clinical benefit of the mCTA for the thrombus length measurement which shows good agreement compared to the

DSA. Thus, we encourage incorporating mCTA into the routine CT stroke fast track imaging protocol for patient selection to endovascular thrombectomy.

Our study had several limitations. First, the study's retrospective design may contribute to the possibility of selection bias. Second, pathological thrombus measurement was not performed, and the linear line drawing measurement method used in our study may underestimate the true thrombus length in the cases with arterial tortuosity. Third, we included only the patients with proximal MCA occlusion, then we cannot apply the mCTA clot length measurement in the other occluded sites, such as intracranial internal carotid artery. Fourth, we measured the thrombus length based on retrograde pial collateral filling of the contrast media outlined the distal occluded site, this measurement method could be limited in the patients with poor collateral status. Nevertheless, patients with poor collateral had low probability of good outcome after the mechanical thrombectomy and could not be the candidates. Last, our sample size was small and the patient outcome was not examined. The study with larger number of patients may be warranted for the greater clinical benefits.

Conclusion

Thrombus length measurement on the mCTA is quite accurate compared to the DSA, simple and helpful for treatment planning. Measurement of the MCA thrombus length on the mCTA can be practically useful in the routine acute stroke imaging for patient selection to mechanical thrombectomy.

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