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ORIGINAL ARTICLE

CT angiography collateral scoring: Correlation with DWI infarct size in proximal middle cerebral artery occlusion stroke within 12 h onset

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KEYWORDS

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Abstract *Purpose:* It had been postulated that intra-cranial collateral flow can maintain penumbra and limit infarct growth in acute stroke patients. CT angiography is a frequently performed non-invasive modality for evaluation of intracranial collaterals. In this study, we sought to assess whether there is correlation between degree of collateral circulation as determined by CTA and admission DWI infarct size.

Patients and methods: We analyzed thirty patients with proximal middle cerebral artery occlusion within 12 h of onset. The grade of CTA intra-cranial collaterals was evaluated using Maas system and modified Tan scale. Admission DWI infarct volumes were calculated. Spearman correlation coefficient was used to assess relationship between CTA collateral score (CS) and DWI infarct size.

Results: Direct inverse correlation was found between CTA CS and infarct volume ($r = -0.5$, $p = 0.001$). ROC analysis showed CS as a good discriminator of DWI volume (AUC = 0.8, $p = 0.001$). Small infarct size was a significant predictor of good CS ($p = 0.01$).

Conclusions: In patients with major acute MCA occlusion strokes, CTA collateral grading is significantly correlated with admission DWI size. This finding may be relevant for clinical practice and helpful for guiding treatment decision and predicting clinical outcome.

1. Introduction

Acute anterior cerebral circulation occlusion is one of the most devastating clinical events, often causing severe neurologic deficit or death. Achieving well timed recanalization remains a main aim of acute stroke care (1) as it reduces tissue at risk and reverses neurologic deficits. The extent of revascularization depends not only on recanalization of the primary arterial occlusive lesion but also on reperfusion of the distal vascular bed (2,3). A lot of factors can impact success of recanalization, including clot composition, extent of clot burden, site of clot impaction, and collateral supply (4–7).

The collateral flow helps to maintain cerebral perfusion in the setting of arterial occlusion. Ischemic penumbra can remain viable because some degree of blood flow is sustained

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through the collateral circulation that includes arterial communications between extracranial and intracranial circulation (8).

In acute ischemic stroke attributable to proximal anterior circulation occlusions, a smaller infarct volume at admission is an important predictor of functional outcome (9,10). Thus, recanalization therapy in acute MCA occlusion should ideally be guided by diagnostic methods capable of accurately identifying irreversible ischemia (9).

Multiple imaging modalities have been described for assessment and grading of intracranial collaterals as CTA and MRA. Detection of infarct core size is best accomplished with high accuracy and full anatomic coverage by using diffusion-weighted MRI (11–13).

Various scoring systems were used for grading of collateral circulations such as Miteff System (14), Maas System (15), Modified Tan Scale (3), Alberta Stroke Program Early CT Score Methodology using a 20-Point Grading Scale (16), and Careggi collateral score (17). However, there is no consensus on the best method to evaluate and grade collaterals (18).

In this study, we sought to assess whether there is any correlation between degree of collateral circulation and initial (admission) infarct core size.

2. Materials and methods

2.1. Patient selection

This study was approved by the ethics committee of our institution during the period between May 2014 and May 2015. The study included 30 consecutive patients with acute ischemic stroke syndrome. The inclusion criteria for the present study were as follows: (1) Time delay between acute stroke onset and imaging within 12 h; (2) CTA of the head showing proximal anterior circulation artery occlusion (i.e. terminal internal carotid artery (ICA) and/or proximal middle cerebral artery (MCA)); (3) DWI scan demonstrating area of true infarct with corresponding dark ADC. The exclusion criteria were as follows: (1) Intracranial hemorrhage or hemorrhagic infarction at non-contrast CT (NCCT); (2) no visible occlusion or small vessel occlusion at CTA; (3) poor CTA or DWI image quality.

National Institute of Health Stroke Scale (NIHSS), being a simple systematic tool providing a quantitative measure of stroke-related neurologic deficit was used to evaluate clinical severity of stroke. The patients were classified according to multi-item neurologic examination of NIHSS into having minor (1–4), moderate (5–15), moderate to severe (16–20) and severe (21–42) stroke (19).

2.2. Image acquisition

2.2.1. CT protocol

The CT scans were obtained with 16 multi-detector scanner (LightSpeed General Electric Medical Systems, USA).

2.2.1.1. Non Contrast CT. Standard NCCT scanning was performed with the following parameters: 120 kV, 180 mA, 2-s scan time, and 5-mm slice thickness.

2.2.1.2. Computed Tomography Angiography. CT angiography was performed from the vertex to the aortic arch following injection of 80–120 ml of Omnipaque 350 (GE Healthcare Inc., Princeton, NJ) at a rate of 3.5 mL/s. SmartPrep was used with a region of interest 1 cm below the carina covering the entire lumen of the ascending aorta. Scanning began with a 10-s delay after the region of interest reached 75 HU. The parameters were 1.25-mm slice thickness, 0.625-mm reconstruction interval, 120 kV, 350–800 mA, and 0.516:1 pitch.

2.2.2. MRI protocol

MR imaging was performed on a 1.5 T Signa whole body scanner (General Electric Medical Systems, USA) with echo planar capabilities. Axial DWI images were obtained using single shot, spin echo planar imaging with the following parameters: TR 5000 ms; TE 80–110 ms. The high b value was 1000 s/mm^2 and the low b value was 0 s/mm^2; field of view 22×22 cm; matrix size 128×128, and slice thickness of 5 mm with a 1-mm inter-slice gap.

2.3. Post processing image analysis

2.3.1. CTA

CTA axial source images were processed to obtain sagittal, coronal, and 3D reformatted images as well as Maximum Intensity Projection (MIP) images, which were used all together with axial source images for evaluation of vessel patency/occlusion, site, size and extent of occlusion.

The CTA images were reviewed and evaluated by two radiologists (Mahmoud M. Higazi and Enas A Abdel Gawad) who had 10 years and 15 years of experience "respectively" in the field of diagnostic radiology, for intracranial collaterals according to two collateral scoring systems: Maas system and Modified Tan Scale. This was done blinded to results of MR DWI to avoid bias.

2.3.1.1. Maas System. The system of Maas et al. (15) is a 5-point score which compares collaterals on affected hemisphere against those on contralateral side using Sylvian fissure vessels as internal controls. The score ranges are 5 (exuberant), 4 (more than those on the contralateral side), 3 (equal to those on the contralateral side), 2 (less than those on the contralateral side), and 1 (no vessel opacification).

2.3.1.2. Modified Tan Scale. The modified scale of Tan et al. (3) is the simplest system that classifies the collaterals as "good" if seen in $\geqslant 50\%$ of the MCA territory and "poor" when they are seen in 50% of the territory. This system allows a rapid assessment and is less prone to differences in opinion.

2.3.2. MRI

Apparent diffusion coefficient (ADC) maps were generated from the diffusion-weighted images for each slice using commercially available software (Functool, General Electric Medical Systems, USA).

The areas of restricted diffusion at DWI with corresponding dark ADC maps were semi-automatically outlined and traced to obtain infarct volume at admission DWI for all patients. Image segmentation and volume measurements were done using a semi-automated commercially available image analysis software program (Image J, Version 1.5 for Windows).

Table 1 Demographic, clinical and imaging data.

	All patients (n = 30)	CS ⩽ 50% (n = 14)	CS ⩾ 50% (n = 16)	p value
Age, y, median (IQR)	70 (55–83)	78 (68–83)	62 (52–80)	0.102
Sex, male, no. (%)	20 (67%)	9 (64%)	11 (69%)	
NIHSS, mean ± (SD)	13 ± (7)	17 ± (5)	9 ± (6)	**0.001**
Lag time, h, mean ± (SD)	5.34 ± (2.29)	5.96 ± (2.59)	5.03 ± (2.04)	0.448
DWI volume, mL, median (IQR)	24.317 (14.049–117.747)	119.381 (28.556–154.470)	15.4590 (12.772–24.318)	**0.009**

IQR: interquartile range and SD: standard deviation.

2.4. Statistical analysis

Continuous data are shown as mean ± SD for normally distributed data, or median ± IQR. We analyzed the differences between different collateral score groups using two tailed Student t test and ANOVA test. Spearman correlation coefficient was used to analyze association of collateral grade with admission DWI infarct size. Logistic regression analyses were performed for independent predictors of good collateral flow. ROC curve was constructed. The statistical analyses were performed using commercially available software (Medcalc, Version 15 for Windows). P value (<0.05) was considered statistically significant.

3. Results

Thirty-eight patients with acute ischemic stroke who met our inclusion criteria were included in this study. Eight scans were excluded due to poor technical quality of CTA, which did not permit reliable scoring. Of the 30 included patients, 20 (67%) patients were males and 17 (57%) patients had right sided stroke. The age of patients ranged between 18 and 92 years. The National Institute of Health Stroke Scale (NIHSS) at arrival ranged between 1 and 24. The mean (±SD) time from onset of symptoms to imaging was 5.3 h (±2.3).

According to Maas scoring system (15), 7 (23%) patients had CS of 1, 7 (23%) patients had CS of 2, 8 (27%) patients had CS of 3, 5 (17%) patients had CS of 4, and 3 (10%) patients had CS of 5.

Based on Modified Tan Scoring system (3), collateral flow was dichotomized into good (⩾50%) and poor (⩽50%) collateral flow. In this study, Maas score of 1 or 2 was designated as poor collateral grades and 3–5 as good collateral grades.

Sixteen (53%) patients had good collateral flow (CS ⩾ 50%). The differences in baseline characteristics between patients with good and poor CS are shown in (Table 1). Poor collateral flow was associated with more clinically severe strokes according to admission NIHSS (p = 0.001).

The median (IQR) admission DWI volumes for patients who had poor collateral flow was 119.381 mL (28.556–154.470). The median (IQR) DWI volume for patients who had good collateral flow was 15.459 mL (12.772–24.318) (p = 0.009, two tailed student t test) (p = 0.009, ANOVA test). The median (IQR) DWI volumes for patients with different collateral scores are illustrated at Fig. 1.

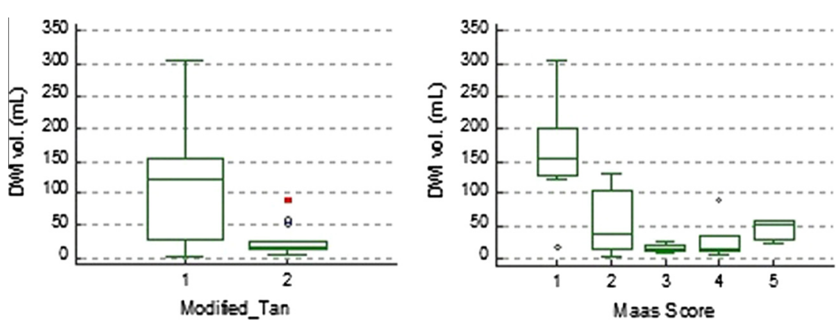

Fig. 1 Multiple comparison graphs showing significant differences between variable groups of Modified Tan score (to the right) and Maas score (to the left) regarding DWI infarct size (p = 0.009, student t test) and (p = 0.0001, ANOVA test) respectively.

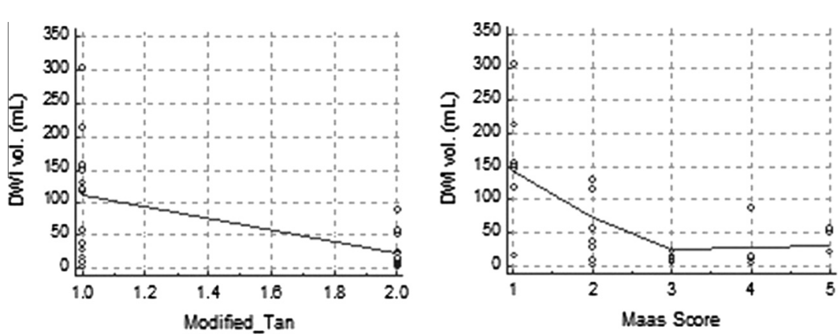

Fig. 2 The correlation analyses revealed significant correlation between admission infarct volume and collateral scoring using MAAS system and Modified Tan system (r = −0.573, p = 0.001) and (r = −0.569, p = 0.001) respectively.

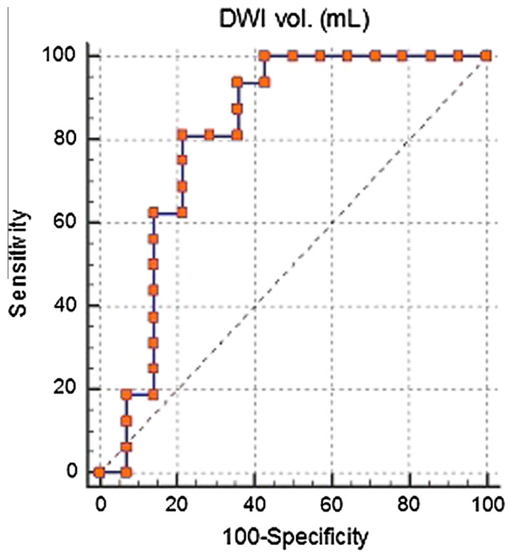

Fig. 3 ROC curve for infarct size prediction of good collateral score (CS ⩾ 50%). Infarct size ⩽24.8 mL was found as optimal cutoff point (AUC = 0.813, 95% CI: 0.629–0.931; $p = 0.001$).

Spearman correlation analyses revealed significant correlation between grade of collateral flow and admission infarct volume using both Maas system and modified Tan system ($r = -0.573$, $p = 0.001$) and ($r = -0.569$, $p = 0.001$) respectively (Fig. 2).

ROC curve analysis (Fig. 3) demonstrated area under curve (0.813) with DWI volume of 24.8 mL as an optimal cutoff point (AUC = 0.813, 95% CI: 0.629–0.931; $p = 0.001$).

In order to further assess predictors associated with good collateral circulation, good CS (CS ⩾ 50% modified Tan and CS > 2 Maas) was used as dependent variable for logistic regression modeling (Table 2). NIHSS at arrival ($p = 0.008$, OR 1.254 per point, 95% CI 1.060–1.484) and admission DWI size ($p = 0.016$, OR 0.971 per mL, 95% CI 0.949–0.994) predicted good CS, but time from onset of symptoms to imaging and age were not significant predictors.

Examples of patients with different grades of collateral scores and their corresponding admission DWI scans are shown in Figs. 4 and 5.

4. Discussion

Collateral flow has an important role in predicting stroke outcome and without adequate collateral flow, irreversible neuronal damage occurs within minutes (20,21).

Multiphase CTA is a non-invasive procedure, which permits assessment of collateral circulation with a single injection of contrast. It is a quick technique and its widespread availability makes it ideal for studying of collateral status for patients with acute stroke (22).

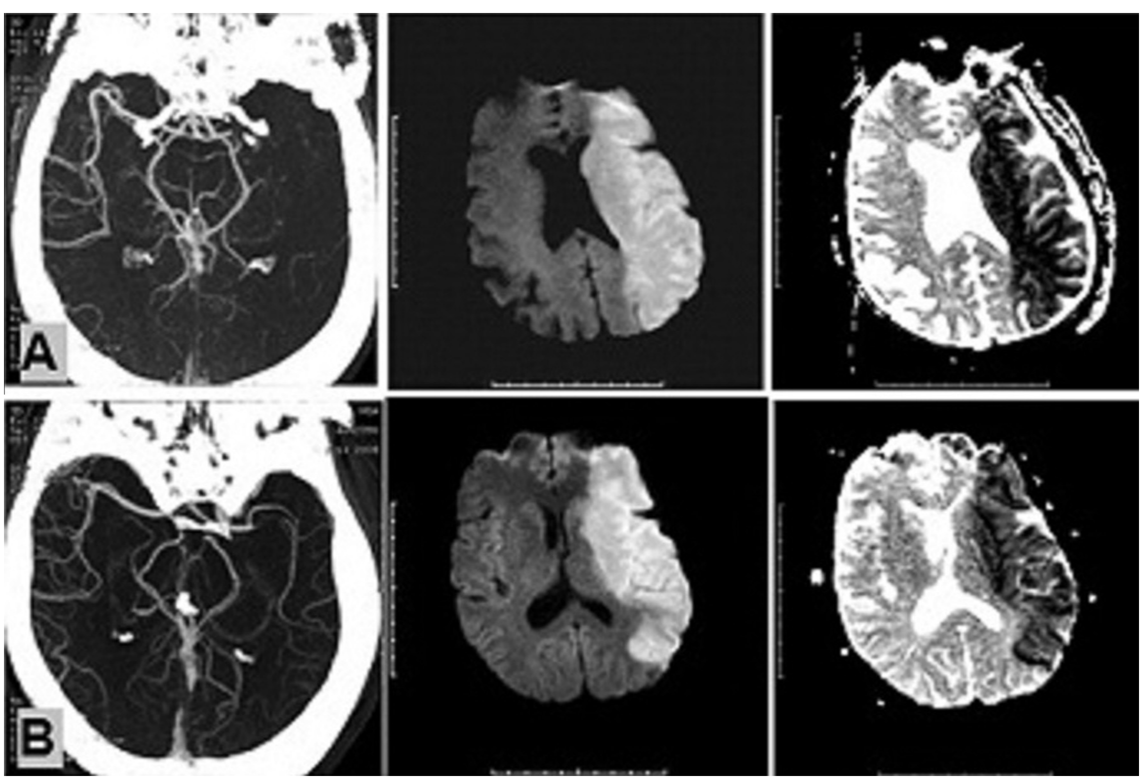

Fig. 4 Axial MIP-CTA and corresponding admission DWI of 2 different cases, each demonstrating poor collateral flow (CS < 50%) along with large infarct size (> 100 mL). (A) 68 y old male imaged 10 h. after onset. NIHSS = 23. CTA revealed CS = 1 (according to Maas scoring system); indicating the absence of collateral flow and DWI with corresponding ADC showed huge infarct volume (303 mL). (B) 51 y old male, presented 7 h. post onset, NIHSS 19, MIP CTA showed CS = 2 (less than unaffected hemisphere) with large DWI volume (135 mL).

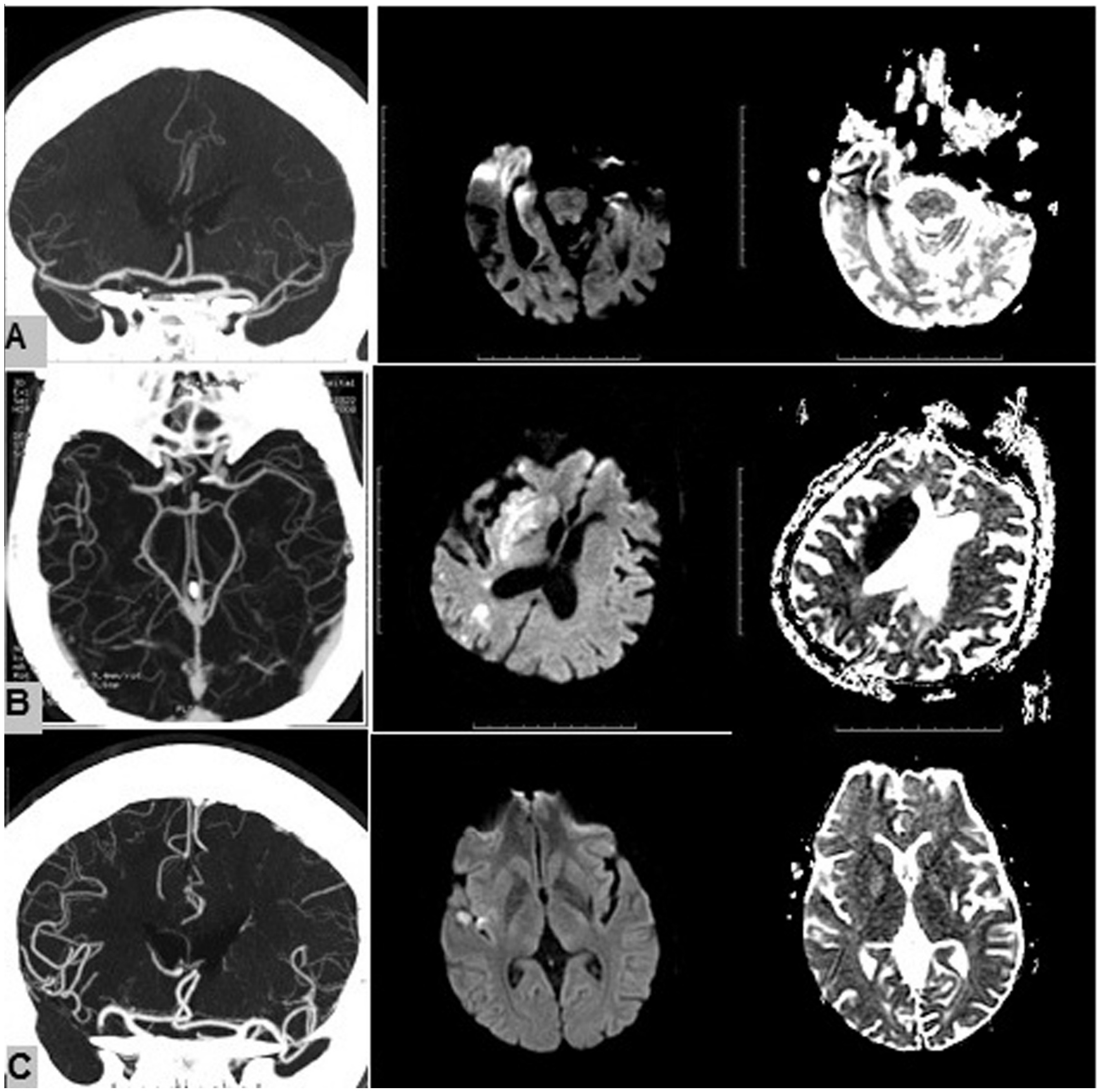

Fig. 5 MIP-CTA and admission DWI of 3 different patients, each demonstrating good collateral flow (CS > 50%) together with corresponding small infarct size (< 70 mL). (A) 52 y old male, 7 h post ictus, NIHSS = 16, CTA CS = 3 (equal to unaffected side) and DWI volume was 52 mL. (B) 57 y old female, 6.5 h post ictus, NIHSS = 18, CTA CS = 4 (more than unaffected hemisphere) and DWI volume = 40 mL. (C) 52 y old female, 5 h post ictus, NIHSS = 5, CTA CS = 5 (exuberant) and DWI volume = 10 mL.

Table 2 Logistic regression analyses for predictors of good CS.

Variable	*p* value	Odds ratio	95% CI
Age	0.118	1.041	0.989–1.095
NIHSS	**0.008**	1.254	1.060–1.484
Lag time (h)	0.938	0.982	0.628–1.536
DWI volume (mL)	**0.016**	0.971	0.949–0.994

We studied correlation between CTA collateral score and DWI admission infarct size in a relatively homogenous group of major proximal anterior circulation acute ischemic stroke patients within 12 h from onset of symptoms.

As regards baseline characteristics, our patients with poor CS appear similar to corresponding populations in other acute ischemic stroke studies. In the DEFUSE study, (11) "malignant profile" patients had a DWI lesion ⩾100 mL, a mean age of 68.3 years, and a median baseline NIHSS score of 18.5. In a study of intra-arterial therapy (23) "futile" patients had a DWI lesion > 70 mL, a mean age of 57.8 years, and a median NIHSS score of 21. In Souza et al. (24) patients with a CTACS = 0 had a median DWI lesion of 165.8 mL, a mean age of 71.4 years, and a median baseline NIHSS score of 21. In comparison, our patients with poor CS had a median DWI volume of 119.381 mL, a median age of 78 years, and a mean baseline NIHSS score of 17.

The results of this study showed that the degree of collateral circulation on admission CTA inversely correlated with admission DWI infarct core in patients with major acute ischemic strokes using Maas system and Modified Tan scoring system. Moreover, using reliable collateral scoring systems, we found that there was a significant difference between admission DWI volumes in patients with poor CS (119.381 mL) and patients with good CS (15.459 mL) with $p = 0.009$. This finding is relevant for clinical practice as it is helpful for guiding treatment decision and predicting clinical outcome.

Souza et al. (24) reported that there was a negative correlation between CTA collaterals and admission DWI lesion volume ($p < .0001$). Also a malignant collateral profile (collateral score of zero) is highly specific for large admission DWI lesion size and poor functional outcome.

Low NIHSS at arrival ($p = 0.008$) and small admission DWI size ($p = 0.016$) were the only predictors for good CS in this study. This coincided with a multivariate analysis of study by Souza et al. (24) in which admission DWI lesion volume ($p < 0.001$) and NIHSS score ($p = 0.007$) were reported to be the only independent variables associated with admission collateral score. Saarinen et al. (12) found that both clot location and CS were highly significant and independent predictors of favorable clinical outcome.

ROC analysis revealed that DWI size was a good discriminator of CTA CS (AUC = 0.813, $p = 0.001$). Moreover, ROC analysis in the study by Souza et al. (24) revealed that collateral score predicted 3-month functional independence for untreated patients (AUC = 0.80, $p = 0.01$).

The results of our study are supported by data of Bang et al. (25) who demonstrated that angiographic collateral grade can determine recanalization rate after endovascular revascularization therapy and that no beneficial effects were observed in patients who had poor collateral and underwent therapeutic recanalization.

This study is not without limitations. Direct data about vessel recanalization or spontaneous reperfusion were not available. CTA may lead to underestimation of collateral circulation because of possible late vessel filling. The impact of CS on patient outcome may vary according to specific pathophysiology of each patient and treatment variables beyond concern of this study, such as rehabilitation or negligence of care.

5. Conclusions

In patients with major acute middle cerebral artery occlusion strokes, CTA collateral grade was significantly correlated with admission DWI size. Poor collateral circulation is a major risk for developing an extensive infarct volume. These findings stress the importance of well-timed correct therapeutic decision-making, as well as avoiding useless/harmful interventional therapeutic recanalization in that subset of patients.

Conflict of interest

The authors declared that there is no conflict of interest.

References

(1) Rha J-H, Saver JL. The impact of recanalization on ischemic stroke outcome: a meta-analysis. Stroke 2007;38:967–73.

(2) Khatri P, Neff J, Broderick JP, Khoury JC, Carrozzella J, Tomsick T. Revascularization end points in stroke interventional trials: recanalization versus reperfusion in IMS-I. Stroke 2005;36:2400–3.

(3) Tan IYL, Demchuk AM, Hopyan J, Zhang L, Gladstone D, Wong K, et al. CT angiography clot burden score and collateral score: correlation with clinical and radiologic outcomes in acute middle cerebral artery infarct. AJNR Am J Neuroradiol 2009;30:525–31.

(4) Mattle HP, Arnold M, Georgiadis D, Baumann C, Nedeltchev K, Benninger D, et al. Comparison of intraarterial and intravenous thrombolysis for ischemic stroke with hyperdense middle cerebral artery sign. Stroke 2008;39:379–83.

(5) Somford DM, Nederkoorn PJ, Rutgers DR, Kappelle LJ, Mali WPTM, van der Grond J. Proximal and distal hyperattenuating middle cerebral artery signs at CT: different prognostic implications. Radiology 2002;223:667–71.

(6) Gralla J, Burkhardt M, Schroth G, El-Koussy M, Reinert M, Nedeltchev K, et al. Occlusion length is a crucial determinant of efficiency and complication rate in thrombectomy for acute ischemic stroke. AJNR Am J Neuroradiol 2008;29:247–52.

(7) Rosenthal ES, Schwamm LH, Roccatagliata L, Coutts SB, Demchuk AM, Schaefer PW, et al. Role of recanalization in acute stroke outcome: rationale for a CT angiogram-based "benefit of recanalization" model. AJNR Am J Neuroradiol 2008;29:1471–5.

(8) Kim JJ, Fischbein NJ, Lu Y, Pham D, Dillon WP. Regional angiographic grading system for collateral flow: correlation with cerebral infarction in patients with middle cerebral artery occlusion. Stroke 2004;35:1340–4.

(9) Jovin TG, Yonas H, Gebel JM, Kanal E, Chang YF, Grahovac SZ, et al. The cortical ischemic core and not the consistently present penumbra is a determinant of clinical outcome in acute middle cerebral artery occlusion. Stroke 2003;34:2426–33.

(10) Hakimelahi R, Vachha BA, Copen WA, Papini GDE, He J, Higazi MM, et al. Time and diffusion lesion size in major anterior circulation ischemic strokes. Stroke 2014;45:2936–41.

(11) Albers GW, Thijs VN, Wechsler L, Kemp S, Schlaug G, Skalabrin E, et al. Magnetic resonance imaging profiles predict clinical response to early reperfusion: the diffusion and perfusion imaging evaluation for understanding stroke evolution (DEFUSE) study. Ann Neurol 2006;60:508–17.

(12) Saarinen JT, Rusanen H, Sillanpää N. Collateral score complements clot location in predicting the outcome of intravenous thrombolysis. AJNR Am J Neuroradiol 2014;35:1892–6.

(13) Rusanen H, Saarinen JT, Sillanpää N. Collateral circulation predicts the size of the infarct core and the proportion of salvageable penumbra in hyperacute ischemic stroke patients treated with intravenous thrombolysis. Cerebrovasc Dis 2015;40:182–90.

(14) Miteff F, Levi CR, Bateman GA, Spratt N, McElduff P, Parsons MW. The independent predictive utility of computed tomography angiographic collateral status in acute ischaemic stroke. Brain 2009;132:2231–8.

(15) Maas MB, Lev MH, Ay H, Singhal AB, Greer DM, Smith WS, et al. Collateral vessels on CT angiography predict outcome in acute ischemic stroke. Stroke 2009;40:3001–5.

(16) Menon BK, Smith EE, Modi J, Patel SK, Bhatia R, Watson TWJ, et al. Regional leptomeningeal score on CT angiography predicts clinical and imaging outcomes in patients with acute anterior circulation occlusions. AJNR Am J Neuroradiol 2011;32: 1640–5.

(17) Mangiafico S, Consoli A, Renieri L, Rosi A, De Renzis A, Vignoli C, et al. Semi-quantitative and qualitative evaluation of pial leptomeningeal collateral circulation in acute ischemic stroke of the anterior circulation: the Careggi Collateral Score. Ital J Anat Embryol 2013;118:277–87.

(18) Yeo LLL, Paliwal P, Teoh HL, Seet RC, Chan BP, Ting E, et al. Assessment of intracranial collaterals on CT angiography in anterior circulation acute ischemic stroke. AJNR Am J Neuroradiol 2015;36:289–94.

(19) Harrison JK, McArthur KS, Quinn TJ. Assessment scales in stroke: clinimetric and clinical considerations. Clin Interv Aging 2013;8:201–11.

(20) Kucinski T, Koch C, Eckert B, Becker V, Krömer H, Heesen C, et al. Collateral circulation is an independent radiological predictor of outcome after thrombolysis in acute ischaemic stroke. Neuroradiology 2003;45:11–8.

(21) Henderson RD et alNorth American Symptomatic Carotid Endarterectomy Trial (NASCET) Group. Angiographically defined collateral circulation and risk of stroke in patients with severe carotid artery stenosis. Stroke 2000;31:128–32.

(22) Menon BK, O'Brien B, Bivard A, Spratt NJ, Demchuk AM, Miteff F, et al. Assessment of leptomeningeal collaterals using dynamic CT angiography in patients with acute ischemic stroke. J Cereb Blood Flow Metab 2013;33:365–71.

(23) Yoo AJ, Chaudhry ZA, Nogueira RG, Lev MH, Schaefer PW, Schwamm LH, et al. Infarct volume is a pivotal biomarker after intra-arterial stroke therapy. Stroke 2012;43:1323–30.

(24) Souza LCS, Yoo AJ, Chaudhry ZA, Payabvash S, Kemmling A, Schaefer PW, et al. Malignant CTA collateral profile is highly specific for large admission DWI infarct core and poor outcome in acute stroke. AJNR Am J Neuroradiol 2012;33: 1331–6.

(25) Bang OY, Saver JL, Kim SJ, Kim G-M, Chung C-S, Ovbiagele B, et al. Collateral flow predicts response to endovascular therapy for acute ischemic stroke. Stroke 2011;42:693–9.