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FULL PAPER

Prominent cortical and medullary veins on susceptibility-weighted images of acute ischaemic stroke

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Objective: To determine the clinical and imaging implications of prominent cortical and medullary veins on susceptibility-weighted images (SWI) of patients with acute stroke.

Methods: Consecutive patients with acute ischaemic stroke who had SWI scan within 24 h of symptom onset or time last-seen-well were included. The SWI series were reviewed for the presence of prominent cortical and medullary veins and were graded independently by two neuroradiologists. The correlations between prominent vein grades with different imaging and clinical variables were determined.

Results: Among 213 patients, prominent SWI cortical and medullary veins were identified in 35 (16.4%) patients and 20 (9.4%) patients, respectively. There was fair interobserver agreement ($k = 0.314$ – 0.338 , $p \leq 0.001$) for grading, and moderate agreement ($k = 0.406$ – 0.413 , $p \leq 0.001$) for the presence of prominent veins. Both prominent cortical and medullary veins were associated with the presence of arterial

occlusion ($\rho = 0.232$, $p = 0.001$; $\rho = 0.180$, $p = 0.008$; respectively) and larger infarct volume ($\rho = 0.445$, $p < 0.001$; $\rho = 0.167$, $p = 0.015$; respectively). However, neither cortical nor medullary cortical veins were associated with the severity of symptoms at admission or clinical outcome. Prominent cortical veins were independent predictors of arterial occlusion ($p = 0.018$), whereas prominent medullary veins were more strongly associated with larger infarct volumes ($p < 0.001$).

Conclusion: There were small but significant correlations between cortical and medullary veins on SWI with arterial occlusion and large infarct volume in acute ischaemic stroke.

Advances in knowledge: In consecutive patients with acute ischaemic stroke within anterior and posterior circulation territories, prominent cortical and medullary veins on SWI series are associated with imaging biomarkers of poor clinical outcome (i.e. large infarct volume and major arterial occlusion).

INTRODUCTION

With its high sensitivity for paramagnetic substances and high resolution, susceptibility-weighted imaging (SWI) has emerged as a crucial MRI technique that is becoming more routinely in use. The SWI sequence has developed into a useful clinical tool in the evaluation of cerebrovascular diseases, including detection of intraparenchymal haemorrhage, venous thrombosis and haemorrhagic transformation of stroke, and even assessment of brain tissue at risk of infarction.^{1–4} The presence of microhaemorrhage, prominent veins and susceptible vein sign on SWI series has been applied for evaluating stroke severity, treatment response and prognosis.^{5–8}

Asymmetrically dilated cortical and medullary veins on SWI have been reported in patients with acute ischaemic stroke.^{9,10} The presence of prominent veins has been

hypothesized to represent an uncoupling between oxygen supply and demand within the hypoperfused tissue, with a relative increase in the deoxyhaemoglobin to oxyhaemoglobin ratio.¹¹ Prominent veins on SWI are thought to represent either ischaemic penumbra or poor collateralization of arterial supply.^{1,9,12,13} However, the appearance of prominent cortical and medullary veins seems to be pathophysiologically complex; thus, their clinical significance remains elusive.

The present study aimed to evaluate the frequency and severity of prominent cortical and medullary veins on SWI in patients with acute ischaemic stroke scanned within 24 h of symptom onset. We also evaluated the relationship between the presence of prominent cortical and medullary veins with arterial occlusion, severity of symptoms, infarct volume and clinical outcome.

METHODS AND MATERIALS

Patients

The prospectively collected clinical and imaging database of consecutive patients with acute ischaemic stroke, in two university-affiliated hospitals, was retrospectively reviewed, between January 2011 and December 2014, constituting a 4-year period. The inclusion criteria were (1) acute ischaemic stroke with no evidence of intracranial haemorrhage; (2) brain MRI performed within 24 h from witnessed symptom onset (or time last-seen-well); (3) interpretable-quality SWI sequence obtained as part of the MRI; (4) and had undergone either simultaneous Magnetic Resonance Angiography (MRA) or Computed tomography angiography (CTA) within 3 h of the MRI scan. Institutional review board approval at both centres was obtained.

Clinical data

The clinical data were obtained from electronic medical records and stroke registry. The initial stroke severity was assessed using the National Institutes of Health Stroke Scale score. Patients received i.v. tissue plasminogen activator and/or intra-arterial (IA) thrombolysis/thrombectomy based on national treatment guidelines in use at the time of presentation.¹⁴ Clinical outcome was assessed based on 3-month modified Rankin Scale (MRS). Poor outcome was defined by a MRS score of >2 .

Image acquisition

Most patients were examined using a 1.5- or 3.0-T MR scanner. The SWI sequence was acquired with the following parameters at 1.5 T (Magnetom Avanto; Siemens Medical Solutions, Erlangen,

Germany): repetition time 34.6 ms; echo time 49.6 ms; flip angle 15°; slice thickness 2 mm; field of view 23 cm. At 3.0 T (Magnetom Tim Trio; Siemens Medical Solutions, Erlangen, Germany), the parameters were: repetition time 27 ms; echo time 20 ms; flip angle 15°; slice thickness 2 mm; field of view 23 cm.

Image analysis

The SWI sequences of all patients were assessed for the presence of prominent cortical and/or medullary veins by two independent reviewers masked from clinical outcome. A 0–3 scoring system was used for the evaluation of prominence grades akin to prior studies: 0 = none, 1 = mild, 2 = moderate and 3 = distinct prominence (Figure 1).^{9,10,12} Arterial occlusion was determined on time-of-flight MRA obtained at the same time as SWI, or—if unavailable—on CTA performed within 3 h of the MRI examination. The diffusion-weighted imaging infarct lesion volumes were manually segmented and measured using the MRIcron software (McCausland Center for Brain Imaging, University of South Carolina, Columbia, SC).

Statistical analysis

The continuous, categorical and ordinal variables are expressed as mean $\pm$ standard deviation, number (percentage) and median (interquartile), respectively, and compared using Student's *t*, Mann–Whitney *U* and χ^2 tests, respectively. Interobserver agreement was determined using Cohen's Kappa. Spearman's correlation test was used to analyze the correlation between ordinal variables (*e.g.* prominent vein grades). Stepwise variable selection was used with binary logistic and linear regression

Figure 1. A 0–3 scoring system was applied for grading of prominent cortical and medullary veins on susceptibility-weighted imaging series compared with contralateral hemisphere. Upper row images from a to c are showing Grades I–III prominent cortical veins (arrows) and lower row images from d to f are showing Grades I–III prominent medullary veins (arrows).

analysis in the determination of independent predictor variables, as appropriate. All analyses were performed using the SPSS® v. 21 (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL). The *p*-value threshold for significance was set to <0.05.

RESULTS

Patient demographics

A total of 213 patients were included. The average patient age was 64.3 ± 17.4 years; 128 (60.0%) patients were male. The median admission National Institutes of Health Stroke Scale score was 4 (interquartile: 2–7). Of these, 173 (81.2%) patients had witnessed stroke; and the rest had wake-up stroke. The MRI scans were obtained 13.9 ± 7.2 h after the symptom onset or the time last-seen-well. Regarding reperfusion therapy, 50 (23.5%) patients received i.v. tissue plasminogen activator; 4 (1.9%) patients had combined IA thrombolysis and thrombectomy. Arterial occlusions were identified in 47 (22.1%) patients; these included 6 occlusions of the internal carotid artery, 29 occlusions of the middle cerebral artery (MCA), 1 occlusion of the anterior cerebral artery, 1 occlusion of the basilar artery and 10 occlusions of the posterior cerebral artery.

Prominent cortical veins

Regarding the grading, and the presence *vs* absence of prominent cortical veins, the interobserver kappa scores were 0.314 ($p < 0.001$) and 0.413 ($p < 0.001$), respectively. In 46/213 (22%) patients, the two reviewers had disagreement with regard to the presence of prominent cortical veins. According to the final consensus review, 17 patients had Grade I, 14 patients had Grade II and 4 patients had Grade III prominent cortical veins (Table 1). Table 2 summarizes the correlations between prominent cortical veins and different clinical and imaging findings. There was significant correlation between the prominent cortical vein grades and the presence of arterial occlusion ($p = 0.001$), as well as infarct volume ($p < 0.001$). An arterial occlusion was found in 15/35 (43%) patients having prominent cortical veins *vs* only 32/178 (18%) of patients lacking prominent cortical veins ($p = 0.003$). The average infarct volume in patients with prominent cortical veins was significantly higher (81.9 ± 144.4 ml) than that in those lacking prominent cortical veins (33.4 ± 71.3 ml, $p = 0.003$). The 1.5-T scanner was used in 5/35 (14%) patients with prominent cortical veins, and 54/178 (30%) patients without prominent cortical veins ($p = 0.063$).

Prominent medullary veins

Regarding the grading of medullary vein prominence, and the determination of the presence *vs* absence of prominent medullary veins, the interobserver kappa values were 0.338 ($p < 0.001$)

and 0.406 ($p < 0.001$), respectively. In 35/213 (15%) patients, the two reviewers had disagreement with regard to the presence of prominent medullary veins. A final consensus review found 11 patients with Grade I, 6 patients with Grade II and 3 patients with Grade III prominent medullary veins (Table 1). A significant correlation was noted between prominent medullary vein grades with the presence of arterial occlusion ($p = 0.008$), infarct volume ($p = 0.015$) and IA treatment ($p = 0.005$), as summarized in Table 2. An arterial occlusion was identified in 9/20 (45%) patients with prominent medullary veins *vs* 38/193 (20%) patients who lacked such veins ($p = 0.019$). The IA treatment was unevenly distributed, with 2/20 (10%) patients with and 2/193 (1%) patients without prominent medullary veins undergoing endovascular intervention. The average infarct volume in patients with prominent medullary cortical veins was significantly higher (120.2 ± 192.6 ml) than that in those without (33.2 ± 65.9 ml, $p < 0.001$). The 1.5-T scanner was used in 2/20 (10%) patients with prominent medullary veins and 57/193 (30%) patients without medullary cortical veins ($p = 0.070$).

Correlation between prominent cortical and medullary veins

There was a significant correlation between cortical and medullary prominent vein grades ($\rho = 0.325$, $p < 0.001$). A total of 10 patients had both prominent cortical and medullary veins (Table 1); among those, 5/10 patients had an arterial occlusion (Figure 2). However, binary logistic regression analysis found that only prominent cortical vein presence had significant association with arterial occlusion (OR = 1.827, 95% confidence interval: 1.109–3.009; $p = 0.018$). *Via* stepwise linear regression analysis, there was a significant association between infarct volume with medullary vein grade ($p < 0.001$), but not with prominent cortical veins ($p = 0.059$).

DISCUSSION

This study set out to determine the frequency and severity of prominent cortical and medullary veins on SWI in patients with acute ischaemic stroke and to determine whether a relationship exists between the presence or grade of prominent cortical and medullary veins with several other clinical and imaging findings. In this regard, prominent cortical veins on SWI were found in 16.4% of patients with acute ischaemic stroke, with prominent medullary veins in 9.4% patients. There was fair to moderate interobserver agreement in the determination of such prominent vein presence and grade. Interestingly, both prominent cortical and medullary veins have small but significant correlations with larger infarct

Table 1. Distribution of prominent cortical and medullary veins

		Prominent medullary vein (grade)				Total
		0	1	2	3	
Prominent cortical vein (grade)	0	168	9	1	0	178
	1	14	1	2	0	17
	2	10	1	2	1	14
	3	1	0	1	2	4
Total		193	11	6	3	213

Table 2. Correlation between prominent cortical and medullary veins with different clinical and imaging findings

	Prominent cortical veins		Prominent medullary veins	
	Spearman rho	<i>p</i> -value	Spearman rho	<i>p</i> -value
Age	−0.097	0.158	−0.115	0.068
Gender	0.123	0.074	0.061	0.372
i.v. tPA treatment	0.016	0.814	0.004	0.959
IA thrombolytic and thrombectomy	0.045	0.510	0.192	0.005 ^a
Onset to scan time gap ^b	−0.015	0.829	−0.029	0.670
Arterial occlusion	0.232	0.001 ^a	0.180	0.008 ^a
Infarct volume	0.445	<0.001 ^c	0.167	0.015 ^d
Admission NIHSS score	0.110	0.110	0.106	0.122
3-month mRS score	0.115	0.095	0.057	0.411

IA, intra-arterial; mRS, modified Rankin Scale; NIHSS, National Institutes of Health Stroke Scale; tPA, tissue plasminogen activator.

^a*p*-value < 0.01.

^bThe time gap between symptom onset or last-seen-well and MRI scan.

^c*p*-value < 0.001.

^d*p*-value < 0.05.

volumes and the presence of an arterial occlusion. However, we found no statistically significant association with severity of symptoms at presentation or 3-month clinical outcome.

This may be the first study to demonstrate a correlation between the presence of prominent cortical and medullary veins on SWI

with infarct volume in patients with acute phase stroke. While the presence of prominent cortical and medullary veins was not directly associated with clinical outcome in this study cohort, such prominent veins correlate with imaging biomarkers of severe hypoperfusion—*i.e.* arterial occlusion and infarct volume. Large infarct lesions on diffusion-weighted imaging have a high

Figure 2. A 34-year-old female presented with right hemiparesis and underwent MRI 11.8h after symptom onset: the susceptibility-weighted imaging (SWI) series are demonstrating moderately prominent cortical (a) and medullary (b) veins (arrows). Notably, the arrow on MRA is pointing to MCA M2 segment occlusion (c), which has appeared as hypointense thrombus on SWI series (the arrow on d).

risk of developing worse clinical outcomes and symptomatic intracranial haemorrhage.^{15,16} Also, proximal intracranial arterial occlusions are independent predictors of poor outcome in acute ischaemic stroke.¹⁷ Hence, a prospective clinical study with uniform field strength and inclusion criteria may identify an association between prominent vessels on admission MRI/SWI scan and clinical outcome in patients with acute strokes.

The presence of asymmetrically prominent cortical or medullary veins on SWI of patients with acute ischaemic stroke has been described previously.^{4,9,10,18,19} Although the correlation between prominent veins with infarct volume or arterial occlusion has barely been tested before, some authors have evaluated the association between the prominent cortical or medullary veins and clinical outcome.^{4,9,10} For example, in a cohort of 44 patients with acute ischaemic stroke scanned within 48 h of onset with 75% rate of MCA occlusion, Huang et al⁴ found 15 (34.1%) patients with prominent veins on SWI. In their series,⁴ the presence of prominent veins was not associated with haemorrhagic transformation and oedema, stroke worsening or improving, or clinical outcome. In contrast, Sun et al⁹ reported a 39/572 (6.8%) rate of asymmetric cortical veins on SWI of patients with stroke, which was associated with early neurological deterioration, the presence of arterial occlusion and poor clinical outcome. Also, Mucke et al¹⁰ reported a 55/86 (64%) rate of prominent medullary veins in patients with MCA territory infarct, which was associated with more severe symptoms at presentation and worse outcome at discharge. Thus, the presence of cortical or medullary veins may still have promise in portending a poor long-term prognosis, given their correlation with imaging biomarkers of severe stroke.

Regarding the pathophysiologic explanation for the presence of prominent veins on SWI, early theories suggest that the phenomenon may be caused by an imbalance between oxygen supply and demand in the hypoperfused tissue and increased oxygen extraction fraction.¹¹ The locally increased ratio of deoxyhaemoglobin to oxyhaemoglobin in cortical and medullary veins might be an expression of ischaemia and represent the degree of hypoperfusion and oxygen extraction.^{20,21} Several studies have indeed shown an association between T_2^* signal drop and increased oxygen extraction fraction.^{20,21} Since the oxygen extraction fraction is increased in the ischaemic penumbra, some authors suggested that prominent hypointense veins on SWI could possibly represent the penumbra.^{4,7} Such a penumbra may diminish, as reperfusion is achieved *via* intervention, or a new perfusion balance is achieved through collateral veins. Prior studies, using gradient-echo T_2^* weighted imaging, have shown that abnormal prominent deep cerebral and superficial cortical veins correlate with perfusion defects and increased cerebral blood volume, suggestive of misery perfusion.^{22,23} Our findings are consistent with the general

consensus that prominent cortical and medullary veins on SWI reflect a state of hypoperfusion in acute ischaemic stroke that usually leads to a relatively large core of infarct volume—commonly in the context of major arterial occlusion. Thus, given the general association between larger infarct volume size and arterial occlusion with poor outcome, the presence of prominent cortical or medullary veins on SWI may help with prognostication of acute ischaemic stroke, although this needs to be validated prospectively.

Several limitations were present in this study besides the inherent limitation of its retrospective nature. First, both 1.5- and 3.0-T magnet scanners were utilized for MRI acquisition, which could result in difference in sensitivities of SWI in detecting such veins; hence, the true frequency of such prominent veins in acute stroke would optimally be determined prospectively *via* a single scanner, preferably at 3.0-T field strength or above with a homogeneous protocol, given the higher degree of magnetic susceptibility with increasing field strength. However, we found no significant difference in the rate of prominent veins among patients scanned with 1.5-T vs 3.0-T scanner. Second, there could be improved detection of such prominent veins with other sequence parameters besides field strength; however, the authors acknowledge that SWI sequence parameters in this study generally followed the routine settings by the vendor, with very little changes. Third, the presence of prominent veins on SWI series may depend on the delay between symptom onset and imaging, although no significant correlation between these imaging findings and the time gap to scan was identified. Fourth, the wide range of reported rate of prominent cortical and medullary veins in the literature and fair to moderate interreviewer agreement in our cohort may reflect the subjectivity of the evaluation and limit its clinical application before standardization of image evaluation. Finally, given that many patients were scanned out of the reperfusion therapy window, extrapolation of data for any treatment decision would be limited, and as mentioned earlier, this necessitates a dedicated, prospective study.

CONCLUSION

In this retrospective study of consecutive patients with acute stroke, a correlation was found between the presence and grade of prominent cortical and medullary veins with larger infarct volumes and the presence of arterial occlusion, but not with outcome. Thus, the findings support previously described theories regarding the pathophysiology of prominent cortical and medullary veins as signs of ischaemia and severe hypoperfusion. Given that large infarct volume and major arterial occlusion are accepted secondary signs of poor clinical outcome, a prospective study with more selective inclusion criteria at higher field strengths could better determine whether there is a true association between the presence of such prominent veins with clinical outcome.

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