European Journal of Radiology 83 (2014) 1448–1454

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Leptomeningeal collateralization in acute ischemic stroke: Impact on prominent cortical veins in susceptibility-weighted imaging

Rajeev K. Verma [a,*,1], Kety Hsieh [a,1], Pascal P. Gratz [a], Adrian C. Schankath [a], Pasquale Mordasini [a], Christoph Zubler [a], Frauke Kellner-Weldon [a], Simon Jung [b], Gerhard Schroth [a], Jan Gralla [a], Marwan El-Koussy [a]

[a] University Institute for Diagnostic and Interventional Neuroradiology, Inselspital, University of Bern, Bern, Switzerland
[b] Department of Neurology, Inselspital, University of Bern, Bern, Switzerland

ARTICLE INFO

Article history:
Received 19 March 2014
Received in revised form 8 May 2014
Accepted 10 May 2014

Keywords:
Acute ischemic stroke
Susceptibility-weighted imaging
Leptomeningeal collateralization
Perfusion-weighted imaging
Prominent cortical veins

ABSTRACT

Background: The extent of hypoperfusion is an important prognostic factor in acute ischemic stroke. Previous studies have postulated that the extent of prominent cortical veins (PCV) on susceptibility-weighted imaging (SWI) reflects the extent of hypoperfusion. Our aim was to investigate, whether there is an association between PCV and the grade of leptomeningeal arterial collateralization in acute ischemic stroke. In addition, we analyzed the correlation between SWI and perfusion-MRI findings.
Methods: 33 patients with acute ischemic stroke due to a thromboembolic M1-segment occlusion underwent MRI followed by digital subtraction angiography (DSA) and were subdivided into two groups with very good to good and moderate to no leptomeningeal collaterals according to the DSA. The extent of PCV on SWI, diffusion restriction (DR) on diffusion-weighted imaging (DWI) and prolonged mean transit time (MTT) on perfusion-imaging were graded according to the Alberta Stroke Program Early CT Score (ASPECTS). The National Institutes of Health Stroke Scale (NIHSS) scores at admission and the time between symptom onset and MRI were documented.
Results: 20 patients showed very good to good and 13 patients poor to no collateralization. PCV-ASPECTS was significantly higher for cases with good leptomeningeal collaterals versus those with poor leptomeningeal collaterals (mean 4.1 versus 2.69; $p = 0.039$). MTT-ASPECTS was significantly lower than PCV-ASPECTS in all 33 patients (mean 1.0 versus 3.5; $p < 0.00$).
Conclusions: In our small study the grade of leptomeningeal collateralization correlates with the extent of PCV in SWI in acute ischemic stroke, due to the deoxyhemoglobin to oxyhemoglobin ratio. Consequently, extensive PCV correlate with poor leptomeningeal collateralization while less pronounced PCV correlate with good leptomeningeal collateralization. Further SWI is a very helpful tool in detecting tissue at risk but cannot replace PWI since MTT detects significantly more ill-perfused areas than SWI, especially in good collateralized subjects.

1. Introduction

The extent of the infarct core, existence of a penumbra and the site of vessel occlusion are the relevant variables which guide the therapeutic decision in the setting of acute ischemic stroke. Good collaterals which can support the blood flow to the penumbra and thus extend the therapeutic window are being increasingly recognized as a further key player in this decision process. Susceptibility-weighted imaging (SWI) is a useful imaging tool routinely applied for detection of blood byproducts, e.g. in hemorrhage and calcifications [1–3]. There is also a role for SWI in acute ischemic stroke. Three main pathological changes were described in this context. First, the susceptibility vessel sign [2,4] that corresponds to the occluding thrombus. Second, detection of hemorrhagic transformation in the infarct [2]. Third, prominent cortical veins (PCV) in the hypoperfused regions [2,5,6]. A possible explanation for the signal drop marking the PCV on SWI is the increased oxygen extraction fraction (OEF) in the critically

* Corresponding author at: Institute for Diagnostic and Interventional Neuroradiology, University Hospital Bern and Inselspital, Freiburgstrasse 4, 3010 Bern, Switzerland. Tel.: +41 31 6321377; fax: +41 31 6321378.
E-mail addresses: rajeev.verma@insel.ch, rajeev.verma@insel.ch, verma@gmx.ch (R.K. Verma).
[1] These authors contributed equally to the study.

http://dx.doi.org/10.1016/j.ejrad.2014.05.001
0720-048X/

hypoperfused parenchyma. The locally increasing ratio of deoxyhemoglobin to oxyhemoglobin in capillaries and veins might be an expression of the stress that the tissue-at-risk is under [7]. The degree of the SWI signal drop in the PCV could vary according to the degree of hypoperfusion and oxygen extraction. Although a direct comparison between SWI and positron emission tomography (PET) images (the gold standard for quantifying OEF) has not yet been performed several studies have shown an association between T2* signal drop and increased OEF [8–11]. Kao et al. showed a significant correlation between the extent of delayed mean transit time (MTT) in perfusion-weighted imaging (DSC) and the extent of PCV on SWI using the Alberta Stroke Program Early CT Score (ASPECTS) [5]. The authors suggest that SWI can be considered an alternative to DSC to assess the penumbra. However, PCV do not appear in every acute ischemic stroke case as shown in several studies [6,12], making SWI a questionable alternative. In a recent prospective study of Huang et al. no association between the presence of PCV in acute ischemic stroke and prognosis, presence of later hemorrhagic transformation, edema and clinical worsening or improvement was found [6].

However, the appearance of PCV seems to be pathophysiologically complex and the clinical importance is still unclear. The aim of our study was to investigate the influence of the leptomeningeal collateralization on PCV on SWI. A good leptomeningeal collateralization has a tissue protective effect in stroke [13,14]. We hypothesize that this protective effect is reflected in the extent and markedness of PCV. The better the leptomeningeal collateralization the lower the deoxyhemoglobin levels and the less PCV should be observed and vice versa. In addition correlations between PCV, prolonged MTT and diffusion-restricted infarction areas were investigated.

2. Methods

2.1. Patients

We retrospectively retrieved data of 144 patients treated at our Stroke Unit from January 2004 to November 2012. Inclusion criteria were an acute thromboembolic occlusion of the M1-segment of the middle cerebral artery, a preinterventional MRI including SWI, DWI and DSC, and a digital subtraction angiography (DSA). Patients were excluded if image quality was insufficient, e.g. due to severe motion artifacts and in cases of internal carotid artery occlusion. Overall, 33 subjects fulfilled the inclusion criteria (15 female; median age 64.0 years, range 14–87) (see Fig. 1). The patients presented with hemiplegia or hemiparesis, with or without aphasia or dysphasia. The initial National Institutes of Health Stroke Scale (NIHSS) scores and time between stroke onset and MRI acquisition were documented when available. The study was performed according to the ethical guidelines of the Canton of Bern and with approval of our institutional review board.

2.2. Data acquisition

Routine Stroke-MRI protocol was acquired in a 1.5 T and a 3 T Siemens scanner (Magnetom Avanto and Magnetom Trio respectively; Siemens, Erlangen, Germany).

Sequence parameters: for the 1.5 Tesla MRI the SWI parameters were: TR 49 ms, TE 40 ms, number of averages 1, FoV read 230 mm, FoV phase 81.3%, voxel size 1.1 mm × 0.9 mm × 1.8 mm, flip angle 15°, acquisition time 2:59 min. Perfusion imaging parameters (DSC): TR 1410 ms, TE 30 ms, number of averages 1, FoV read 230 mm, FoV phase 100%, voxel size 1.8 mm × 1.8 mm × 5.0 mm, flip angle 90°, acquisition time 2:00 min. DWI parameters: TR 3000 ms, TE 89 ms, number of averages 4, FoV read 230 ms, FoV phase 100%, voxel size 1.2 mm × 1.2 mm × 5.0 mm, acquisition time 1:35 min.

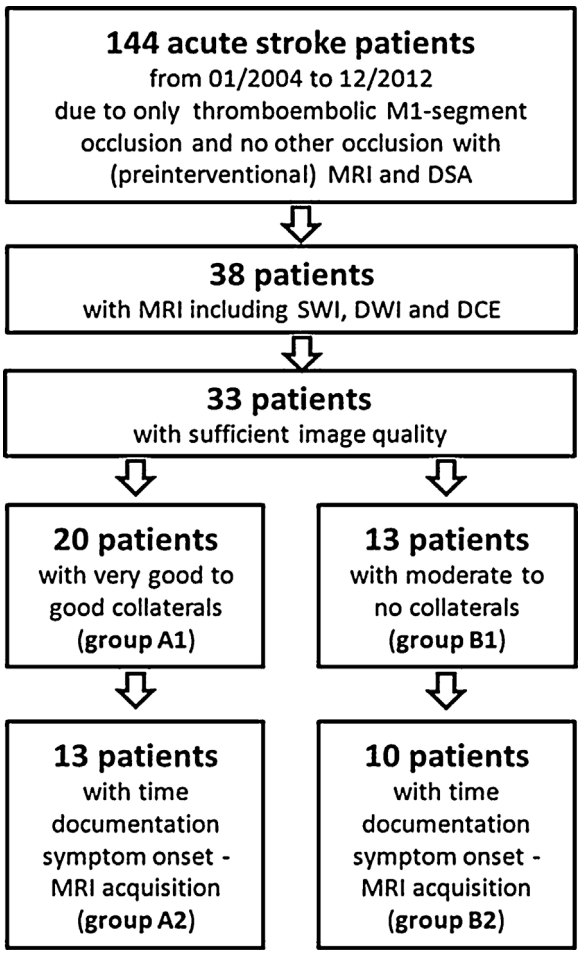

Fig. 1. Overview of patient selection and patient groups.

For the 3 Tesla scanner the SWI parameters were as follows: TR 27 ms, TE 20 ms, number of averages 1, FoV read 230 mm, FoV phase 75.0%, voxel size 0.9 mm × 0.9 mm × 2.0 mm, flip angle 15°, acquisition time 2:59 min perfusion imaging parameters (DSC): TR 1400 ms, TE 29 ms, number of averages 1, FoV read 230 mm, FoV phase 100%, voxel size 1.8 mm × 1.8 mm × 5.0 mm, flip angle 90°, acquisition time 1:59 min. DWI parameters: TR 3500 ms, TE 89 ms, number of averages 4, FoV read 230 ms, FoV phase 100%, voxel size 1.8 mm × 1.8 mm × 4.0 mm, acquisition time 1:15 min.

For both scanners tracer concentration–time curves of the perfusion sequence were analyzed using Siemens Workstations to obtain non-quantitative color-coded maps of Mean Transit Time (MTT). SWI and minimum intensity projections (mIP) images were generated automatically by the scanner software.

2.3. Data analysis

All images were evaluated using our picture archiving and communication system (PACS). Collaterals were classified into the following groups: poor or no, if none or minimal leptomeningeal anastomoses were visualized and no or minimal filling of the occluded vessel territory was seen, and good or very good, if leptomeningeal anastomoses filled the occluded vessel territory by more than half [15]. In case of disagreements a consensus was found by the readers.

ASPECTS, a 10-point semiquantitative CT scoring system, was used to assess the extent of abnormalities on SWI, DWI and DSC