

# The Assessment of Vessel Size Index and its Application in Patients with Ischemic Stroke

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## Introduction

Vessel size imaging (VSI) has been proposed as a quantitative measure of mean diameter of cerebral vessels, which might be of importance in cerebrovascular diseases. This quantitative technique requires the measurement of apparent diffusion coefficient (ADC) and the accurate evaluation of cerebral blood volume (CBV), which were not available in previous studies. This study is on the purpose of the implementation and evaluation of VSI with a specified post processing and establishing VSI measurement on patients with ischemic stroke.

## Methods

**MRI measurement:** Nine healthy volunteers and two stroke patients were examined on a 3.0 Tesla clinical scanner (Tim Trio, Siemens AG, Erlangen, Germany). T2 and T2\*-weighted images were acquired from a hybrid single-shot gradient echo and spin echo sequence with 70 repetitions ( $TE_{GE} = 22$  ms;  $TE_{SE} = 85$  ms;  $TR = 1880$ ms;  $FOV 230$ mm; slice thickness 5mm; 16 slices; matrix size  $64 \times 64$ ). A dose of 0.13mL Gadobutrol (Gadovist, Bayer Schering Pharma AG, Berlin, Germany) /kg body weight was injected at 4 mL/s followed by 30mL saline flush with a time delay of 18 seconds. To obtain ADC value, six-directional diffusion-weighted imaging was performed with  $b = 1000$  s/mm<sup>2</sup>. **Postprocessing:** The mean vessel diameter in each voxel was given as:  $\rho = 1.734(\zeta D)^{1/2} \Delta R_{2GE} / \Delta R_{2SE}^{3/2}$ , where  $\zeta$  is cerebral blood volume (CBV) normalized to a global average of 3%,  $D$  is the diffusion coefficient and set to the ADC, and  $\Delta R_{2GE}$  and  $\Delta R_{2SE}$  are the changes in the transversal relaxation rates [1]. The vessel diameter was calculated by fitting the linear dependence between  $\Delta R_{2GE}$  and  $\Delta R_{2SE}^{3/2}$  [2]. The relative CBV maps were calculated online at the scanner using the manufacturer's software package. ADC maps were coregistered to the VSI images in the application of SPM8 (Wellcome Department of Imaging Neuroscience, University College London, UK).

## Results

Table 1 lists the mean vessel diameter in all nine subjects obtained in the selected ROIs, which are cortical gray matter (GM), white matter (WM) and thalamus (TH). The GM ROI restricts to voxels with a diffusion coefficient of  $0.8 \pm 0.1$   $\mu\text{m}^2/\text{ms}$  in order to exclude voxels contaminated by cerebral-spinal fluid (CSF). In the thalamus with the absence of large vessels, the vessel size is very similar to the value of 14.4  $\mu\text{m}$  proposed by the tissue model [1]. Larger vessel sizes are observed in gray matter than white matter.

The VSI in Patient 1 was performed in acute stroke stage (day 1). On the VSI map on day 1 (Fig 1a), the slightly decreasing vessel size is observed in the area with perfusion deficits compared to the contralateral hemisphere. In the FLAIR lesion (day 6) representing the final infarcted area (Fig. 1f), the vessel diameters are smaller than those in the left hemisphere. For quantitative analysis, three ROIs were defined and mirrored to the left hemisphere for normalisation (Table 2). Vessel size did not show any difference between hemispheres in the recovered tissue (ROI A). In contrast, it was markedly decreased in the final infarcted area in both regions outside the acute DWI lesion (ROI B) and inside it (ROI C).

Patient 2 with right-hemispheric MCA infarction was examined on day 4 after onset of symptoms (Fig 2). Within the demarcation of FLAIR, the VSI map displays hypointensities in the infarcted area compared to the contralateral hemisphere with the ratio of  $0.53 \pm 0.13$ .

## Discussion

The evaluation of CBV is the main source of introducing error for assessing vessel diameter. Kiselev et al. [1] purposed 6% as the averaged CBV, which was accepted as the case for PET [3]. That is mainly the reason for a twofold overestimated relative to the intrinsic modelling in [1]. For MRI studies, 3% is believed to be the proper value [3]. Larger vessel diameter in GM than WM could be explained by a generally higher blood supply and the involvement of larger vessels in GM. The example shown in Fig 1 suggests that the reduction in vessel diameter in the acute stage may correlate to the final infarct size. Further studies are necessary to test the hypothesis of this correlation. The situation is complicated by the indirect nature of the VSI. Results can be biased due to a complex interplay between the involved parameters, even after normalisation on the contralateral regions. With the limitation of insufficient statistics and intersubject comparison, the variation observed in the infarcted region in chronic stage on VSI the map is not fully understood. Figure 3 demonstrates the patterns of the bolus passage in the final infarct region in chronic stages. The magnitude of the curve is determined by the peak tracer concentration. The magnitude reduction on the affected side is partially explained by the reduction in the ADC and the CBV. The rest depends on the vessel size, uncontrolled tracer concentration and possible variation in the vascular structure. Note that such ROI-based results do not coincide with the voxel-based averaging because of nonlinear functional dependence.

## Conclusion

VSI measurement is feasible for the clinical examination in stroke patients. Given the limitations of small number of patients, hypointensities on VSI maps in acute and chronic stage have been observed in areas of the final infarction. The recovered tissue showed normal VSI in the acute phase. Further studies are needed to examine the correlation between the variation in VSI and cerebral ischemia.

## Reference

[1] V. Kiselev et al. *Magn Reson Med* (2005) [2] P. Gall et al. *ISMRM* (2007) [3] L. Østergaard et al. *J Cereb Blood Flow Metab* (1999)

Table 1 Mean vessel diameter over selected ROIs in nine subjects.

Subjects	GM( $\mu\text{m}$ )	WM( $\mu\text{m}$ )	TH( $\mu\text{m}$ )
S1	22.5	20.2	17.1
S2	22.9	18.4	16.8
S3	12.8	10.9	13.1
S4	21.4	15.2	15.2
S5	17.2	16.8	14.7
S6	24.7	20.0	14.2
S7	25.3	18.8	11.3
S8	23.8	19.0	18.2
S9	23.9	18.7	12.9
mean $\pm$ SD	21.6 $\pm$ 3.8	17.5 $\pm$ 2.8	14.8 $\pm$ 2.1

Table 2 The ratios of mean vessel size in ROIs between affected and contralateral hemisphere. SD accounts for the interslice variability

	ROI A	ROI B	ROI C
Mean $\pm$ SD	0.98 $\pm$ 0.05	0.67 $\pm$ 0.14	0.54 $\pm$ 0.38

Fig. 3 Dependence between  $\Delta R_{2GE}$  and  $\Delta R_{2SE}^{3/2}$  during the bolus passage in the area matching final infarction (blue) and the contralateral ROI (red) in Patient 2

