Quantification of brain perfusion in patients with internal carotid stenosis and perfusion change after carotid stenting based on dynamic susceptibility contrast-enhanced MRI

M-Y. Su[1], H-L. Kao[2], Y-W. Wu[2], H-Y. Yu[3], W-C. Chu[4], and W-Y. I. Tseng[5]

[1]Institute of Biomedical Engineering, Natioanl Yang-Ming University, Taipei, Taiwan, [2]Internal Medicine, National Taiwan University Hospital, [3]Surgery, Natioanl Taiwan University Hospital, [4]Institute of Biomedical Engineering, Natioanl Yang-Ming University, [5]Center for Optoelectronic Biomedicine, National Taiwan University College of Medicine

Introduction

In patients with internal carotid artery (ICA) stenosis, the risk of stroke is associated with the reduction of brain perfusion. To reduce the risk, carotid stenting (CAS) has been considered a treatment of choice (1). The change in brain perfusion after CAS, however, still remains unclear. Dynamic susceptibility contrast-enhanced (DSC) MRI is a clinically feasible technique to measure cerebral blood flow (CBF), cerebral blood volume (CBV) and mean transit time (MTT) in patients with ICA stenosis (2). To quantify these perfusion indices, various mathematical and numerical deconvolution approaches have been proposed. In this study, we proposed a model-independent deconvolution method and Tikhonov's regularization to obtain a stable residue function, from which MTT and CBF can be directly computed. We aimed to demonstrate the usefulness of this method by applying to patients with ICA stenosis and comparing the brain perfusion before and 3 months after CAS.

Materials and Methods

Study protocol Six patients with carotid duplex (Dopascan) documented single-site ICA stenosis (>70%) were enrolled in this study. All subjects underwent T_2*- weighted DSC MRI studies, one at baseline (before CAS) and one at 3 months after CAS. MRI scanning was performed on a 3T MR scanner (Tiro, Siemens, Erlangen, Germany).

Image acquisition A time series of 60 consecutive T_2*- weighted DSC images were acquired covering the whole brain using SE-EPI pulse sequence (TR = 2510ms, TE = 47 ms, $\alpha = 90°$, in-plane resolution = 1.98 mm x 1.98 mm, slice thicknes = 3.9 mm). T1-shortening Gd chelates (Gd-DTPA, 0.1mmole/kg) was bolus injected via left antecubital vein at a rate of 4~6ml/sec, commencing on the 5^{th} image in the series.

Image analysis The arterial input function (AIF) was determined from the image which was distal from the circle of Willis by using the independent component analysis (3). Pixelwise cerebral blood flow (CBF), cerebral blood volume (CBV) and mean transit time (MTT) were quantified by model-independent deconvolution and Tikhonov's regularization to reduce oscillations of the residue function (4). From the resulted residue function, CBF was determined by the initial height of the residue function and MTT was determined by integrating this function over time. After obtaining the CBF and MTT, CBV was determined by the product of CBF and MTT according to the central volume theorem (5). To assess the brain perfusion difference, the brain perfusion indices obtained from the hemispheres ipsilateral to the ICA stenosis were compared to those from the contralateral hemispheres. Paired comparison between pre- and post-CAS in each perfusion indices were also analyzed.

Statistical Analysis Data were presented as mean ± SD. The differences of each perfusion index obtained from the stenosed hemispheres and the non-stenosed hemispheres were tested using nonparametric Mann-Whitney test. Paired pre- and post-CAS in each perfusion indices were analyzed using a Wilcoxon signed rank test. Statistical significance was considered if $p<0.05$.

Results

Compared with the contralateral hemispheres, ipsilateral hemispheres showed no significant impairment of CBF (50.5 ± 8.6 ml/100g/min *vs.* 52.2 ± 9.5 ml/100g/min, p = NS) but significant increase in CBV (3.72 ± 0.47ml/100g *vs.* 4.13 ± 0.50 ml/100g, p = 0.034) and MTT (6.82 ± 1.52 sec *vs.* 4.08 ± 1.12 sec, p < 0.001) before CAS (Fig. 1). Three months after CAS treatment, the differences of CBV and MTT between these two hemispheres became insignificant (3.37 ± 0.64ml/100g *vs.* 3.52 ± 0.43 ml/100g, p = NS; 5.22 ± 0.84 sec *vs.* 5.17 ± 0.98 sec, p = NS)(Fig. 1). Figure 2 demonstrates the mapping of MTT in a patient with left ICA stenosis. Note that before CAS, MTT in the left hemisphere was definitely prolonged relative to MTT in the right hemisphere. Three months after CAS, MTT in the left hemisphere returned to normal level.

Conclusion

In six patients with ICA stenosis, MTT showed the most significant change, followed by CBV in the hemispheres ipsilateral to ICA stenosis. Three months after CAS treatment, no significant difference in all perfusion indices was found between two hemispheres. Our results indicate that MTT is the most sensitive indicator to detect the perfusion deficit in patients with ICA stenosis, and that CAS is an effective procedure to restore the brain perfusion. In conclusion, the proposed model-independent deconvolution method combined with Tikhonov's regularization is potentially useful in detecting compromised brain perfusion and its recovery after intervention.

References

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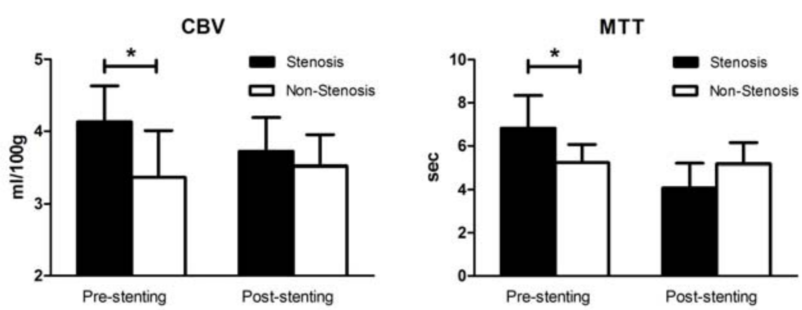

Fig 1. Comparisons are made between the stenosed and non-stenosed hemispheres in CBV and MTT before and after CAS treatment.

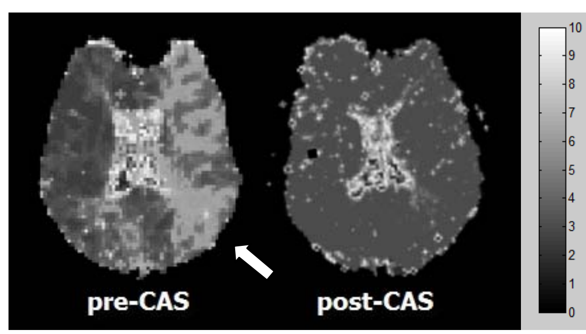

Fig 2. MTT in the hemisphere ipsilateral to the ICA stenosis (arrow) was longer than MTT in the contralateral hemisphere before CAS treatment. After carotid stenting, the difference in MTT between two hemispheres disappeared.