

# REFERENCE-BASED CBF INDEX OF MAXIMUM UPSLOPE WITHOUT USING ARTERIAL INPUT FUNCTION IN DYNAMIC SUSCEPTIBILITY CONTRAST MRI: COMPARISON WITH DECONVOLUTION METHOD

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## Introduction

Accurate measurements of arterial input function (AIF) are indispensable for quantification of perfusion parameters such as MTT, CBV and CBF based on the indicator dilution theory in perfusion imaging using vascular contrast materials. Quantification of cerebral perfusion using deconvolution methods with DSC-MRI has been reported on [1-2]. However, accurately measuring AIF in DSC-MRI is difficult due to non-linearity and the limited dynamic range between  $\Delta R2^*$  and the concentration of contrast media. Relative perfusion parameters without measuring AIF have been widely employed [3]. We have presented that the reference-based CBF, named CBFratio, using maximum upslope (US) of tissue time-intensity curve [4] without AIF was practical because errors were insignificant compared to the other non-AIF based CBF indexes [5,6], and transit delay time errors could be neglected even in the stroke patients [5]. The purpose of this study was to assess errors in the CBFratios obtained using US and block-circulant SVD (cSVD) [7], by using numerical simulation with adding noise, and to assess clinical results.

## Methods

The ideal quantification of DSC-MRI data is analyzed based on the following Indicator dilution theory:  $C(t) = CBF \cdot K_a \int_{-\infty}^t C_a(t-\tau)R(t-\tau)d\tau$  (1) where  $C_a(t)$  and  $C(t)$  are respectively AIF and time intensity curve for tissue,  $K_a$  is a scaling factor depending on hematocrit difference between capillaries and large vessels, AIF is an arterial input function, and  $R(t)$  is a residue function  $R(t)$ . Almost the same simulation design as Wu's study [7] was used. AIF was modeled by a gamma-variate function:  $C_a(t) = k^a \exp[-t/b]: t \geq 0, = 0: otherwise$  (2) of  $a=3$  and  $b=1.5$  (peak time=4.5 s).  $C(t)$  was generated based on Eq. [1] with triangular  $R(t)$  with delay  $t_0=6$  s and  $MTT=1\sim 24$  s. Sampling interval for AIF and  $C(t)$  was 1.5 s. Gaussian noises corresponding baseline SNRs of 100, 50 and 20 were added only on the original tissue signal before converting  $\Delta R2^*$ . In fitting  $C(t)$  by Eq. [2] using least squares fitting, truncation time was decided as  $PT_0+8$  s for eliminating recirculation. US was obtained by the slope at the 1<sup>st</sup> inflection point of fitted  $C(t)$ . In cSVD method, threshold parameter  $P_{svd}$  (defined the ratio of the largest singular value and element) was set at 0.05~0.2, and CBF was obtained by the maximum of  $R(t)$ . CBF was calculated every 1000 times then those mean and SD were calculated.  $CBV=4$  ml/100cc and  $WM$  ( $CBF=40$ ml/100cc/min,  $MTT=6$  s) was selected for the reference to the CBFratio. Clinical DSC-MRI were performed on 1.5T MRI (EXCELART VantageTM, Toshiba Medical Systems) using a gradient echo echo-planar sequence (TR/TE=1500/60 ms, 128x128, 6-mm slice thickness, 14 slices, 45 phases). The CBF indexes were obtained using the US and cSVD methods, the CBFratio maps were obtained by the references which were set on the normal hemispheres, and then maps were displayed with window-level=1 and window-width=2. Here free software "PMA" (8) was used for making cSVD map and displaying the results.

## Results and Discussions

In comparison with the errors in the CBFratio (Fig. 1), US and cSVD provided equivalent errors (both mean and SD) in higher CBF. The CBFratio with cSVD was overestimated in lower CBF since CBF was obtained as peak height of deconvolved  $R(t)$ . Table 1 shows the average of relative error in CBF and the CBFratio ranging from 10 to 100 every 10 [ml/100cc/min]. The US CBFratio demonstrated that the mean is the least (<10 %) and the SD is on a comparable level with the cSVD. It should be further noted that both mean and SD of errors in CBFratio particularly in lower CBF were reduced than those of errors in CBF. Clinical results (Fig.2) showed that the slopes of linear regression between the absolute values of US and cSVD-CBF differed depending on  $P_{svd}$  for cSVD even in a single subject, i.e., the slopes for  $P_{svd} = 0.05, 0.1$  and  $0.2$  were respectively 1.20, 1.45 and 1.68. However, the correlation coefficients were very good ( $r>0.9$ ). The two CBFratio maps obtained by normalizing with the each normal hemisphere were also well correlated visually independent of  $P_{svd}$ , as a result of the correlation linearity between those absolute values being well retained. Our results also lead to the availability of reference-based approach even in cSVD. We can conclude that the CBFratio obtained with US provided the better CBF index balancing accuracy as well as simplicity than the CBF and CBFratio with cSVD, though further clinical validation is might be required.

## Acknowledgement

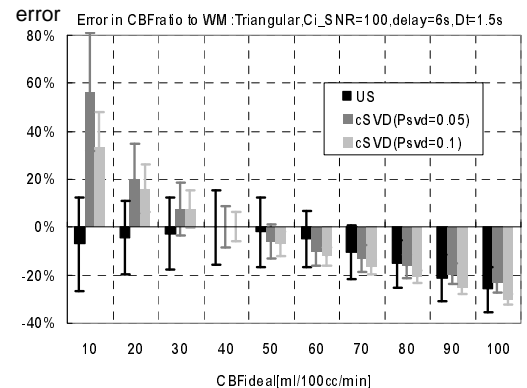
We thank T. Kodama, M.D. in Miyazaki University for providing clinical data.

## References

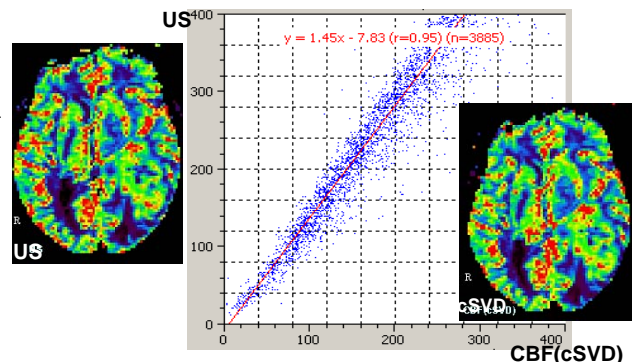
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**Table.1** Simulated of relative errors (average mean and SD [%]) obtained by different methods. The CBFratio with US provided the best results.

| CBF index         | Method                 | SNR= $\infty$ | SNR=100         | SNR=50          | SNR=20          |
|-------------------|------------------------|---------------|-----------------|-----------------|-----------------|
|                   |                        |               | no ise on C     | no ise on C     | no ise on C     |
| error in CBF      | US (fit)               | 20.1          | 23.3 $\pm$ 11.2 | 23.7 $\pm$ 16.8 | 17.9 $\pm$ 29.5 |
|                   | cSVD( $P_{svd}=0.05$ ) | 16.8          | 19.9 $\pm$ 8.2  | 26.9 $\pm$ 15.2 | 60.4 $\pm$ 35.2 |
|                   | cSVD( $P_{svd}=0.1$ )  | 22.1          | 22.7 $\pm$ 4.9  | 24.4 $\pm$ 8.8  | 34.0 $\pm$ 19.4 |
| error in CBFratio | US (fit)               | 7.4           | 9.4 $\pm$ 13.2  | 10.4 $\pm$ 19.7 | 9.8 $\pm$ 32.9  |
|                   | cSVD( $P_{svd}=0.05$ ) | 10.7          | 17.2 $\pm$ 9.1  | 26.7 $\pm$ 15.4 | 47.7 $\pm$ 26.7 |
|                   | cSVD( $P_{svd}=0.1$ )  | 17.4          | 16.9 $\pm$ 5.8  | 20.6 $\pm$ 10.2 | 33.8 $\pm$ 20.0 |



**Fig. 1** Errors in CBFratio as a function of  $CBF_{ideal}$  for noise-added simulation, obtained by using the US and cSVD ( $P_{svd} = 0.05, 0.1$ ) methods. Errors are shown by mean $\pm$ SD. Note that the US and the cSVD provided equivalent errors in higher CBF



**Fig. 2** Pixel-by-pixel correlation between cSVD ( $P_{svd}=0.1$ ) (x) and US (y) for clinical data demonstrated excellent linear correlation ( $r>0.9$ ). Two CBFratio maps obtained by normalizing with the each normal (right) hemisphere also provided excellent correlations.