Dynamic susceptibility MRI with a pre-bolus administration design for improved absolute quantification of perfusion

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Purpose

Reproducible absolute quantification of cerebral blood volume (CBV) and cerebral blood flow (CBF) by dynamic susceptibility contrast MRI (DSC-MRI) is difficult to achieve, for example, due to partial-volume effects (PVEs). Rescaling of the arterial input function (AIF) using a corrected venous output function (VOF) in DSC-MRI has been shown to improve the correlation between CBF estimates obtained by DSC-MRI and Xe-133 SPECT [1]. However, the VOF obtained from the superior sagittal sinus is often distorted at peak concentration by signal displacement caused by the low bandwidth of the single-shot GRE-EPI [2] and by signal saturation at the high TE required to obtain adequate signal reduction in tissue [3]. The purpose of this study was to correct for arterial PVEs by rescaling the AIF using a VOF obtained by injecting a fraction of the contrast-agent dose as a pre-bolus [4]. During the pre-bolus passage, a segmented EPI sequence in single-slice mode was used to register the VOF in the superior sagittal sinus. Using segmented EPI, a higher bandwidth can be used to avoid large-vessel geometric distortion during the bolus passage. Furthermore, since the brain tissue is not the target of this part of the examination, a short TE can be used during the pre-bolus passage to avoid large-vessel signal saturation.

Methods

Four subjects (age 37-61 years, 3 men and 1 woman) were examined on a 3 T MR unit (Philips Achieva, Philips Medical Systems, Best, The Netherlands). First, a pre-bolus of contrast agent was administered (20% of 0.1 mmol/kg b.w.) and a segmented EPI (TE/TR/FA=15ms/135ms/22°) with ETL=7 was used to track the pre-bolus passage through the superior sagittal sinus in one single slice (spatial resolution=1.72×1.72×5 mm^3) with a temporal resolution of 0.81 s. Thereafter, the remainder of the contrast-agent dose was administered (i.e. 80% of 0.1 mmol/kg) and the actual DSC-MRI experiment was performed using a single-shot GRE-EPI (TE/TR/FA=29ms/1360ms/90°) providing 23 slices (spatial resolution=1.72×1.72×5 mm^3). A ROI was chosen in the superior sagittal sinus to obtain the VOF from the pre-bolus data. The pre-bolus VOF area was then multiplied by four to obtain the same dose response as in the DSC-MRI experiment executed at larger dose. An AIF from the Sylvian-fissure region was retrieved from the single-shot GRE-EPI time series and then modified according to Eq. 1.

$$C_{AIF\,rescaled}(t) = \frac{\int VOF(t)\,dt}{\int C_{AIF\,original}(t)\,dt} C_{AIF\,original}(t) \qquad (1)$$

CBV and CBF were calculated according to standard DSC-MRI procedures, including block-circulant SVD deconvolution [5, 6]. All subjects gave written informed consent before participation.

Results

Table 1 shows the perfusion estimates obtained in grey matter (GM) and white matter (WM) using the proposed technique. In Figure 1, CBV and CBF maps from one subject are displayed. Figure 2 shows a VOF and an original AIF from one subject. Noise-induced fluctuations and recirculation contributions were removed, and the VOF was multiplied by four to match the dose in the single-shot GRE-EPI experiment.

Table 1. CBV and CBF obtained in the four subjects.

Subject	Sex	Age	Area(VOF)/ Area(AIF)	CBF (GM) ml/min 100g	CBF (WM) ml/min 100g	CBV (GM) ml/100g	CBV (WM) ml/ 100g
1	F	37	3.9	78	31	5.8	2.7
2	M	61	5.8	69	26	6.9	3.3
3	M	52	4.2	77	31	5.2	2.6
4	M	45	1.7	49	21	7.0	3.0
Mean±SD		**49±10**	**3.9±1.7**	**68±13**	**27±4.8**	**6.2±0.9**	**2.9±0.3**

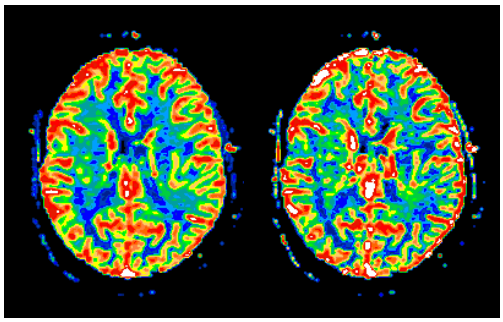

Figure 1. Maps of CBF (left) and CBV (right) obtained from one subject.

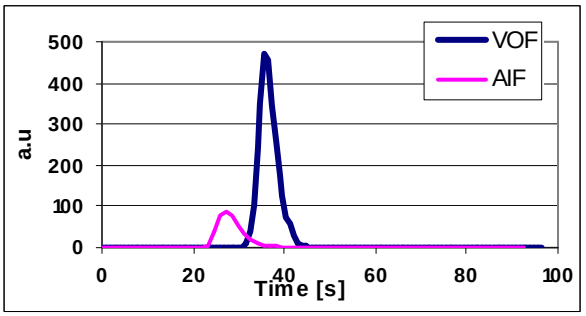

Figure 2. Examples of VOF and original AIF obtained from one subject.

Discussion

Quantitative values obtained with the proposed technique approached those typically obtained by gold-standard techniques such as PET and Xe-CT. The mean ratio Area(VOF)/Area(AIF) of 3.9 indicates that our proposed correction method removes a substantial amount of arterial PVEs. Any residual overestimation of CBV and CBF using DSC-MRI could be explained by a difference in contrast-agent response between tissue and large vessels [7-8] and a non-linear ΔR_2*-vs-concentration relationship [9]. T1 effects that can be present at short TRs are considered to be limited due to the fresh inflow of blood in the vein. Furthermore, the mean transit time in the brain is around 4-6 s and the blood that was excited in the arteries in the slice perpendicular to the superior sagittal sinus is assumed to be fully relaxed when it reaches this large vein.

References

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