Optimizing perfusion imaging of brain tumors: Validation of venous output function used as a surrogate AIF

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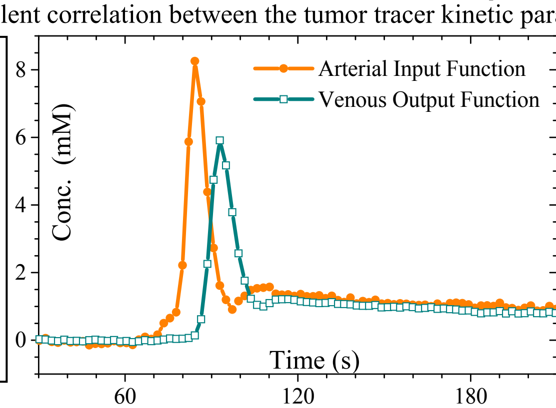
Introduction: In dynamic contrast enhanced (DCE-) MRI studies of human brain tumors, a sufficiently large artery for the arterial input function (AIF) is often not available in the imaging volume. It is thus common practice to use the venous output function (VOF) in the superior sagittal sinus (SSS) as a surrogate AIF. However, to our knowledge no DCE-MRI study has ever validated this practice for high-temporal-resolution data ($\Delta t \leq 2$ s) used for first-pass kinetics (1). With conventional magnitude data, it is difficult to compare AIFs and VOFs in the same patient, since both functions must be measured in a central portion of a 3D volume, due to slab profile and inflow effects (2,3). Using MR signal phase, however, accurate AIFs and VOFs can be measured at any slice location, even for single slices (4). In this work, we acquired phase-derived AIFs and VOFs simultaneously during DCE-MRI brain tumor studies, with the hypothesis that tracer kinetic parameters measured in tumor would be the same using either vascular function.

Methods: Magnitude and phase data were saved from 28 DCE-MRI brain tumor studies (1.5T Siemens Symphony, phased array head coil + neck coil). A 2D SPGR sequence was used: TR=46 ms, double TE=2.06 & 5.48 ms, flip angle=90 deg, thickness=5.5 mm, gap=2.75 mm, 4 transverse slices through the tumor and SSS and 1 separate slice through the carotid arteries, Δt=2.2 s, total 3.6 min, Gd dose=0.1 mmol/kg. Carotid artery AIF, and SSS VOF, were calculated using the phase of the MR signal (4). The peak height, Area Under the Curve's first-pass section (AUC_{fp}), and Washout (mean from 65-90 s after the peak) were measured for all vascular functions, as well as for a published population AIF (5), with AIF versus VOF characteristics compared with a paired t-test. The DCE magnitude data was used to obtain Gd concentration-vs-time in tumor. This was accomplished via the Bookend Method, which used T_1 maps acquired before & after DCE using the variable flip angle method (TR/TE=50/2.16, flip angles=10,20,40,70 deg) (6,7). Tumor K^{trans} (transfer constant), v_p (plasma volume), and v_e (distribution volume) were calculated using the AIF and VOF (the latter temporally shifted to match the AIF timing) for the first 8 studies (calculations ongoing for the remaining cases) (8). Tracer kinetic parameters for AIF versus VOF were compared via an error-weighted linear fit and Pearson's correlation coefficient (R).

Results: A delay of 6.5-8.5 s between AIF and VOF was observed and some dispersion was also apparent. The mean AIF peak height was significantly greater than the mean VOF peak height ($p<0.0001$). Mean AUC_{fp} and Washout were not significantly different between AIF and VOF. There was excellent correlation between the tumor tracer kinetic parameters obtained using AIF and VOF.

Fig 1 (Left): Average AIF (N=25) and VOF (N=28) (VOF not time-shifted for this graph.) 3 AIFs were excluded due to lack of SNR, from failure to add the neck coil.

Fig 2 (Right): AIF versus VOF tumor K^{trans}. Solid orange line = linear fit. Dotted blue line = line of identity.



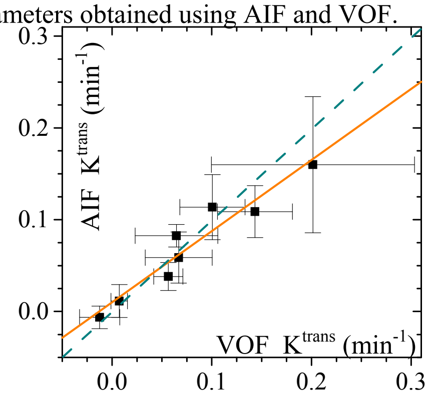


Table 1: AIF & VOF characteristics

	Peak (mM)	AUC_{fp} (mM s)	Washout (mM)
AIF (5)	7.1	58	1.1
AIF	8.3 ± 2.6	77 ± 24	1.1 ± 0.5
VOF	6.2 ± 2.1	70 ± 22	1.0 ± 0.4

Table 2: Linear fit of tumor perfusion parameters AIF versus VOF

Param.	Linear fit	R
K^{trans}	AIF = (0.77± 0.09)*VOF + (0.010 ± 0.009)	0.96
v_p	AIF = (1.0 ± 0.3)*VOF + (0.000 ± 0.004)	0.81
v_e	AIF = (1.4 ± 0.3)*VOF + (0.00 ± 0.12)	0.86

Discussion: The AIF and VOF curve characteristics (esp. AUC_{fp} equivalence) are consistent with the literature, thereby further supporting the phase technique (5,9). The equal AUC_{fp}, equal washout height, and excellent correlation of tumor parameters support the hypothesis that a time shifted VOF can be used in place of the AIF. This suggests that for the tracer kinetic model applied to this study, the differences in peak height and dispersion between the AIF and VOF do not significantly influence the parameters.

Conclusion: For DCE-MRI of human brain tumors, the venous output function in the superior sagittal sinus, which is often easier to measure than the arterial input function (AIF), can be used in the tracer kinetic modeling as a good approximation to the AIF.

References: 1. Ewing et al. MRM 2003;50:283. 2. Roberts et al. ISMRM 2009;2278. 3. Zhang et al. JMRI 2009;30 :656. 4. Foottit et al. MRM 2010;63:772. 5. Parker et al. MRM 2006;56:993. 6. Cron et al. MRM 1999;42:746. 7. Fram et al. MRI 1987;5:201. 8. Tofts et al. JMRI 1999;10:223. 9. Axel. Radiology 1980;137:679.
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