Intra-operative perfusion imaging of brain tumors using dynamic contrast enhanced MRI: A comparison with dynamic susceptibility contrast MRI

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Purpose: Dynamic contrast-enhanced (DCE) and dynamic susceptibility-contrast (DSC) MRI have their own advantages and limitations in the assessment of tumor physiology (1, 2). Few studies of intra-operative MRI for more precise brain tumor resection have employed the DCE (iDCE) and DSC (iDSC) techniques (2). With the nature of this two techniques, one may expect that DSC provides better SNR in mapping cerebral blood volume (CBV) while DCE offers additional information on vessel permeability. Another consideration specific to intra-operative MRI is that the operation-associated blood and trapped air may cause susceptibility artifacts that distort the iDSC results. Such problem may be mitigated by the T1-weighted image acquisition in iDCE. Our goal is to perform qualitative and quantitative comparisons between the two techniques as applied in brain tumors.

Materials and Methods: Three patients sustained intra-axial brain tumors underwent intra-operative MRI studies shortly after surgical resection. The MRI scans were applied with a 1.5 T Magnetom Espree scanner (Siemens, Erlangen, Germany) in the operation room. To obtain the baseline T_{10} maps, a 3D-FLASH sequence with varied flip angles was applied before the contrast injection, with TR/TE = 4.5/1.96 ms, flip angle = 2, 5, 10, 20, 30 degrees, field-of-view (FOV) = 256 mm x 256 mm, matrix size = 256 x 128 or 128 x 128. The same sequence and parameters with a fixed flip angle of 30 degree, was used for the T_1-weighted DCE-MRI. Sixty dynamic phases were acquired during a total acquisition time of 5 min, with a sampling interval of 5 s. The mTK model was used to quantify the volume transfer constant (K^{trans}), the volume fractions of the blood (V_P) and the extravascular extracellular space (V_e) (1):

$$C_t(t) = V_p C_p(t) + K^{trans} \int_0^t C_p(\tau) \cdot e^{-\frac{K^{trans}}{V_e}(t-\tau)} d\tau \quad [1]$$

The arterial input function, C_p, was measured from the internal carotid artery. For either scan, a bolus of 0.1 mm/kg Gd-DTPA (Magnevist, Schering, Berlin, Germany) was injected through an antecubital vein of the patients using a power injector with an injection rate of 4mL/s. Post-contrast T_1-weighted images were acquired between the two dynamic scans using a conventional spin-echo sequence. The DSC-MRI was applied using a dynamic single-shot gradient-echo EPI sequence with TR/TE/FA = 1500 ms/40 ms/90°, acquisition matrix = 128× 128, and FOV = 230 mm× 230 mm. Sixty phases were acquired with a total acquisition time of 90 seconds. Considering possible leakage of contrast agent, the Weisskoff model (4) was applied to the DSC-MRI data analysis:

$$\Delta R_2^*(t) = K_1 \overline{\Delta R_2^*}(t) - K_2 \int_0^t \overline{\Delta R_2^*}(t)\, dt \quad [2]$$

, where $\overline{\Delta R_2^*}(t)$ is the mean normal tissue time curve, and K_2 is considered a permeability-related parameter. The corrected $\Delta R^*_{2,cor}(t)$ is defined by:

$$\Delta R^*_{2,cor}(t) \equiv \Delta R_2^*(t) + K_2 \int_0^t \overline{\Delta R_2^*}(t) dt \quad [3]$$

which used to calculate the relative CBV. The V_p and CBV normalized to a white matter ROI (nV_p and nCBV), K^{trans} and K_2 values were determined for normal tissue and tumor regions for comparisons of the two techniques.

Results: Figure 1 demonstrated that regions with distortions in iDSC-MRI-derived nCBV map (c) were significantly improved by iDCE-MRI. iDCE-MRI provided blood volume map (b) with similar contrast but nosier appearance than the iDSC(c). For quantitative comparisons, Table 1 shows no statistical difference between the mean nV_p and nCBV in the three regions of normal brain tissues. Figure 2 illustrated that iDCE-MRI derived K^{trans} map was more representative of permeability and correlated better with the extent of enhancement pattern seen on post-contrast T_1-weighted image, whereas K_2 map reflected the mixed edema change and permeability, presumably related to the artifact inevitably present in the intra-operative MRI.

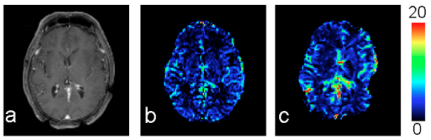

Figure 1. T1w image (a), nVp (b) and nCBV map (c) from patient 1. Both nV_P and nCBV values were normalized to deep white matter.

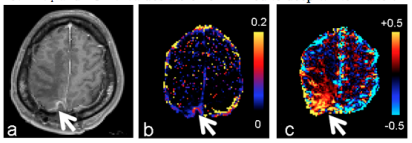

Figure 2. Post-contrast T1w image (a), K^{trans} (b) and K_2 map (c) from patient 2.

Table 1. Mean values of nV_P and nCBV obtained from ROIs in frontal gray matter (GM), occipital GM and thalamus.

Patient No.	Frontal GM		Occipital GM		Thalamus	
	nV_P	nCBV	nV_P	nCBV	nV_P	nCBV
1	2.2	2.4	3.5	3.4	2.7	2.4
2	2.4	2.4	2.5	2.1	1.3	1.3
3	2.7	2.3	3.2	2.7	3.0	2.9
Mean ±	2.4 ±	2.3 ±	3.0 ±	2.7 ±	2.3 ±	2.2 ±
SD	0.3	0.1	0.5	0.6	0.9	0.8
P§	0.65		0.11		0.18	

§: Wilcoxon Signed Ranks Test

Conclusion: The findings of the better representative of permeability by K^{trans} map and less image distortions are arguably for iDCE-MRI to be more valuable for the clinical need of intra-operative assessment of sufficiency of tumor resection. In addition, that no discrepancy between the nV_P and nCBV values is suggestive of the comparative capability of the parameters derived from DCE-MRI in terms of assessing the tumor physiology, long biased on DSC-MRI results.

References: [1]Tofts et al, JMRI: 1997, [2]Boxerman et al, AJNR: 2006, [3]Ulmer et al, Neuroimage: 2009,2010 [4]Weisskoff et al., In Proc. SMR 1999