Evaluation of the Errors in the Measured Dynamic Contrast Enhancement with TWIST View Sharing Using a Novel Simulation Strategy

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Target Audience Radiologists, MRI physicists and scientists.

Introduction: The impact of Time-resolved angiography With Stochastic Trajectories (TWIST) view sharing on breast DCE-MRI has been evaluated previously with digital tumor phantoms and generic image reconstruction algorithms [1-4]. More realistic simulations were performed using acquired raw data of an irregular tumor phantom and the reconstruction algorithm implemented on a clinical scanner for use in this research study only. Such an approach provides a more realistic evaluation of the error in spatial and temporal features of contrast enhancement with respect to different TWIST parameters, which aids the optimization of a clinical DCE-MRI protocol.

Methods: A fractal tumor phantom was first designed based on the diffusion-limited aggregation model[5] and then convolved with a sphere with of diameter 0.5 mm, 3D printed in PLA cubes as a cavity and filled with 0.2mM Gd-BOPTA solution (Fig. 1). The size of the final 'tumor' was 0.71 x 0.74 x 1.28 cm^3. TWIST acquisitions[2] were simulated offline with the acquired raw data using a full k-space acquisition for the pre-contrast and the last post-contrast time points, and partial k-space acquisitions in between. Parameters include: TR = 5 ms; FOV = 160 x 160 x 92 mm^3; acquisition matrix = 192 x 192 x 88; percentage of the central k-space region size (pA) = 10%, 15%, 20%, 25%, and 30%; peripheral region k-space update rate (pB) =10%, 20%, 25%, 33% and 50%. The raw data created were then modulated with "wash-out" and "persistent" type of enhancement curves separately, and each combined with the acquired raw data of a uniform background phantom using a prototypical software, resulted in two set of synthesized raw data. Images were then reconstructed from these synthesized data. The RMS error of percent enhancement of all time points (RMS_{All}) and at peak enhancement (or 60sec post-contrast for "persistent" enhancement) (RMS_{Peak}),[2, 6] as well as the irregularity[7] of the tumor at peak enhancement were estimated. These parameters were defined as:

$$RMS_{all} = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\frac{1}{T}\sum_{t=1}^{T}\left(enhancement_{measured}(t) - enhancement_{true}(t)\right)^2}, \quad RMS_{peak} = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(enhancement_{measured}(t) - enhancement_{true}(t)\right)^2}, \text{ and}$$

$$Irregularity = 1 - \frac{\pi \cdot effective\ diameter^2}{surface\ of\ lesion}, \text{ where } effective\ diameter = 2\cdot\sqrt[3]{\frac{3\cdot lesion\ volume}{4\pi}}$$

Results Fig.2 shows simulated tumor images along the "wash-out" and "persistent" enhancement curves (pA = 10%, pB = 20%). For both types of enhancement, there was little difference between RMS_{All} and RMS_{Peak} in the simulated range of pAs and pBs. Fig 3. shows RMS_{All}, RMS_{Peak}, and irregularity as a function of pA and pB.For minimizing RMS_{All} and RMS_{Peak}, the combinations of pA =10-15% and B =20%- 33% would be optimal. The measured irregularity was lower for wash-out enhancement and higher for persistent enhancement for most pA/pBs compared with 'true' value, and minimum error in the irregularity measurement located at pB = 20%.

Discussions Using a fractal tumor model with highly spiculated margin, the impact of TWIST view sharing reveals a more complex behavior than previous results with a 'regular' tumor. The enhanced 'tumors' from this study show strong edge artifact and complicated enhancement pattern in the initial uptake phase, while toward the end of the curve, such artifacts become less obvious (arrow in Fig 2). This may be caused by the backward sharing of the peripheral k-space data manifesting as an edge-enhancing effect during the initial uptake phase. Magnetic susceptibility between the 'tumor' and PLA may also contribute as a source of error. However, the RMS errors were in general low for both types of enhancements, suggesting that the TWIST view sharing can provide accurate measurement of dynamic contrast enhancement even in irregular tumor shape. The impact of TWIST view sharing on shape irregularity seemed to be less predictable and depends on the shape of both tumor and the enhancement curve.

Reference 1.Song, T., et al., Magn Reson Med, 2009. 61(5): p. 1242-8. 2. Le, Y., et al., J Magn Reson Imaging, 2013. 38(5): p. 1033-42. 3.Herrmann, K. H., et al., in J Magn Reson Imaging, 2011. 34(4): p. 973-82. 4. Janka, R., et al., in *ISMRM* 2010: Stockholm, Sweden. p. 4553. 5. Rashidnasab, A., et al., Physics in Medicine and Biology, 2013. 58(16): p. 5613-5627. 6. Le, Y., et al., in *ISMRM*. 2014: Milan, Italy. p. 6436. 7. Agliozzo, S., et al., Med Phys, 2012. 39(4): p. 1704-15.

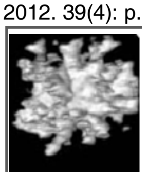

Fig 1. MIP reconstruction of the 3D MR image sets of a printed tumor phantom.

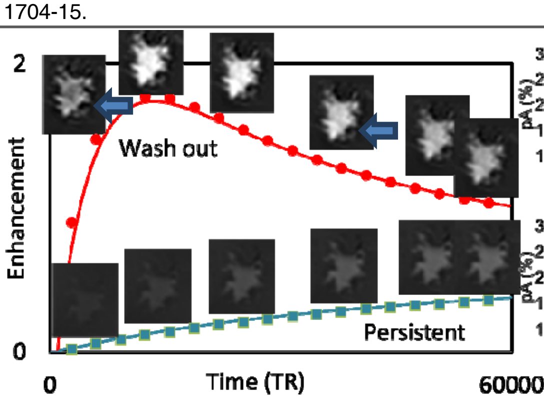

Fig 2. Dynamic enhancement of 'tumor' with wash-out and persistent type of enhancement curve. Solid lines are the 'real' enhancement; Solid dots represent the average enhancement inside the 'tumor'

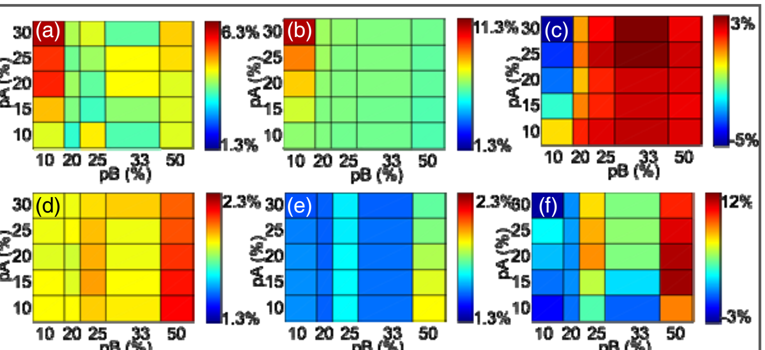

Fig 3. Percentage error of measured enhancement in washout (top) and persistent (bottom) type enhancement. (a)(d): RMS error along the whole enhancement curve; (b)(e) RMS error of the whole tumor at the 1st post-contrast time point and (c)(f): irregularity error of detected 'tumors' with (a-c) washout and (d-f) persistent enhancement.