Introduction: Transcatheter arterial embolization (TAE) and chemoembolization (TACE) are established treatment methods for unresectable liver tumor. Transcatheter Intraarterial Perfusion (TRIP)-MRI is an intra-procedural technique to monitor liver tumor perfusion changes during TAE [1] and TACE [2]. However, previous developed TRIP-MRI approaches either used semi-quantitative perfusion analysis methods which have poorly-defined links to blood flow, or used a peak gradient method [3] which can oversimplify the description of contrast tracer kinetics, to calculate blood flow. In this study, we presented a potentially superior quantitative TRIP-MRI perfusion analysis approach, and evaluated its efficacy in a gel perfusion phantom and in rabbits with VX2 liver tumors during TAE.

Methods: All experiments were performed using a 1.5T clinical MRI scanner (Siemens Magnetom Espree). In phantom studies, we used a chromatography column packed with Sephadex gel as a perfusion phantom. The phantom flow rate was adjusted from 24 mL/min to 2 mL/min at a 2 mL/min interval, and TRIP-MRI measurement was performed at each flow rate. In animal studies, we surgically implanted VX2 carcinoma into the left liver lobe of 12 rabbits. 3 weeks after implantation, we catheterized each rabbit under angiographic guidance to super-selectively deliver 40-120 µm embolic microspheres to liver tumors. After rabbits were transfer to MRI scanner, TRIP-MRI measurements were performed before and after TAE. A quantitative TRIP-MRI measurement involved 3D B1 mapping using catalyzed double-angle method (60°/120°) [4], baseline 3D R1 mapping using GRE variable flip angle method (2°, 9°, 15°, 19°), and dynamic 3D R1 mapping using dynamic GRE sequence at 15° flip angle after intraarterial injection of Gd-DTPA contrast agent. Other dynamic imaging parameters included: phantom studies: TR/TE = 5/1.62 ms, 320×160×40 mm 3 FOV, 1.2 sec sampling rate; animal studies: TR/TE = 6/1.62 ms, 200×113×40 mm 3 FOV, 1.6 sec sampling rate. With B1 calibration and baseline R10 map, an R1 map time series and further contrast concentration map series were derived from each TRIP-MR image series [3]. We applied the commonly used bolus injection temporarily suppress antegrade blood flow and control the maximum vascular contrast agent concentration at the catheter tip immediately proximal to the tumor tissues, we estimated C(t) using prior information about the bolus injection parameters (Eq. 2).

\[ C_x(t) = \alpha \left[ \begin{array}{c} t < 0 \\ t > T_{end} \\ T_{end} \leq t \leq T_{end} \end{array} \right] \]

where \( C_x(t) \) is a normalized boxcar function, with 0 meaning no contrast solution being injected, 1 meaning contrast solution being injected, and \( T_{start} \) and \( T_{end} \) representing the beginning and ending times for the transcatheter injection of the contrast solution. Perfusion maps were generated by fitting combined Eqs. 1 and 2. As \( K_{trans} \) is primarily representative of blood flow under flow-limited conditions expected in extra-cranial tumor microvasculature, we therefore chose \( K_{trans} \) as the kinetic parameter to reflect liver tumor perfusion alterations during TAE. Whole tumor regions-of-interest were drawn on \( K_{trans} \) maps to measure intra-procedural tumor \( K_{trans} \) values. \( K_{trans} \) values before and after TAE were compared using paired t-tests with \( \alpha = 0.05 \).

Results: The phantom \( C(t) \) curves, estimated \( C_x(t) \) curves, and associated model curve fittings for different flow rates are shown in Fig. 1. The measured \( K_{trans} \) demonstrated a strong linear correlation to flow rate during our perfusion phantom studies (\( R^2 = 0.9876, P < .0001 \), Fig. 2). In animal studies, TAE and quantitative TRIP-MRI were successfully performed in 12 rabbits with 19 liver tumors. Fig. 3 shows representative voxel-wise tumor \( C(t) \) curves, estimated \( C_x(t) \) curves, and associated model curve fittings from two representative rabbits. Fig. 4 shows T2-weighted image, TRIP-MRI peak enhanced image, and corresponding \( K_{trans} \) maps before and after TAE from one representative rabbit. The tumor \( K_{trans} \) decreased significantly from 0.468 (95% CI: 0.328-0.607) pre-TAE to 0.093 (95% CI: 0.061-0.126) post-TAE (1 min, P < .0001), with a mean percentage reduction of 77.8% (95% CI: 70.3%-85.3%).

Conclusions: Our study successfully evaluated the efficacy of the proposed perfusion analysis method for TRIP-MRI datasets in a perfusion phantom, and demonstrated the use of quantitative TRIP-MRI to monitor reductions in liver tumor perfusion during TAE. Quantitative TRIP-MRI measurements offer the potential to target optimal embolic endpoint for TAE and TACE, which maximizes tumor response and minimizes toxicity to normal liver tissues.


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