Characterizing cerebral blood volume and permeability with a undersampled multiple-echo 3D projection reconstruction sequence and a fast T1 mapping method

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INTRODUCTION

Dynamic contrast-enhanced MRI (DCE-MRI) has been applied to characterize tissue parameters such as cerebral blood volume (CBV) and permeability in brain tumors by fitting tracer kinetic models (1). Although T1-weighted imaging with whole brain coverage and high temporal and spatial resolution is desired in these applications, current acquisition techniques often compromise either resolution or coverage especially in the slice encoding/selecting direction for temporal resolution. Meanwhile, fitting the tracer models require estimating the tissue tracer concentration from MR signal intensity, which in turn requires a fast and robust method for tissue T1 mapping prior to contrast injection. We demonstrate here the use of a multiple-echo undersampled 3D projection reconstruction sequence (ME-VIPR) (2)) to efficiently image the entire brain with high temporal and spatial resolution. The short TR available with this sequence achieved optimal signals at low flip angles, and therefore the signal equation could be simplified to achieve fast T1 mapping by a linearly fitting process similar to DESPOT1 (3). The applications of these techniques to estimate CBV and permeability were demonstrated in brain tumor patients.

MATERIALS AND METHODS

The pulse sequence for a four-half-echo implementation of the ME-VIPR is shown in Fig. 1. This sequence was implemented in a spoiled gradient recalled echo mode to obtain T1-weighted images. The short TR achieved by this sequence achieved optimal signal at low flip angles. Human imaging was conducted on a 3T scanner (GE Healthcare, Milwaukee, WI) after consent was obtained. Acquisition parameters included receive bandwidth/FOV/flip angle/TR/TE1=62.5 kHz/24 cm/15°/3.16 ms/0.27 ms, equivalent image matrix=80 × 80 × 80. A total of 30 time frames were collected in each experiment at a temporal resolution of 10s/frame. The contrast agent (Omniscan gadodiamide, 0.2ml/kg at 5 ml/s) was injected at the 6th frame. For T1 mapping, five addition acquisitions were performed with small flip angles from 2.5° to 12.5° in a 2.5° step in 50 seconds, giving a total of six flip angles for T1 mapping. Eddy currents induced by the readout gradients were corrected with data collected in less than 5s prior to imaging. The total scan time including T1 mapping is ~6 minutes.

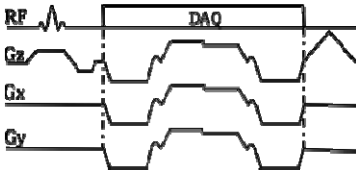

Fig.1 Gradient waveforms of a four-half-echo ME-VIPR sequence.

To map T1, the MR signal $S = M_0 \sin\alpha \frac{1-e^{-TR/T1}}{1-e^{-TR/T1}\cos\alpha}$ [1] was simplified as $S = \frac{M_0\alpha}{1+\frac{T1}{2TR}\alpha^2}$ [2] since $e^{-TR/T1} \approx 1-TR/T1$, $\sin\alpha \approx \alpha$, and $\cos\alpha \approx 1-\alpha^2/2$ when TR<<T1 and α<<1. M_0 is the apparent spin density and α the flip angle in radian. Eq. [2] was rewritten as $S/\alpha = -T1\frac{S\alpha}{2TR} + M_0$ [3], and T1 and M_0 were then extracted with a linear fitting process with S/α and $S\alpha/(2TR)$ the new known variables. By replacing α with $k\alpha$ in equations [2] and [3], where *k is* the relative B1 scale, the impact of B1 inhomogeneity on the measured T1, denoted as $T1_m$ and apparent spin density, denoted as M_{0m} became apparent: $T1_m = T1_{act}k^2$ and $M_{0m} = M_{0act}k$, with $T1_{act}$ and M_{0act} being the actual T1 and apparent spin density, respectively, as was shown in (4). Tissue contrast agent concentration was then estimated at each time frame and fitted to a simple Patlak model (5) to estimate CBV and permeability.

RESULTS AND DISCUSSION

Representative signal intensity images during the dynamic acquisition are shown in Fig. 2a. Whole brain coverage is achieved with isotropic resolution and high SNR. Fig. 2b shows the corresponding T1 maps obtained without B1 inhomogeneity correction. The T1 values in the white matter and gray matter are ~800 ms and ~1000 ms in the central brain sections and ~3000 ms in the CSF. Impact of B1 inhomogeneity is seen across the FOV, indicating the need for B1 mapping. Nevertheless, the calculated CBV and permeability maps are shown in Fig. 2c and d, respectively. This subject shows regions of increased blood volume and permeability within the lesion, likely indicating a tumor recurrence.

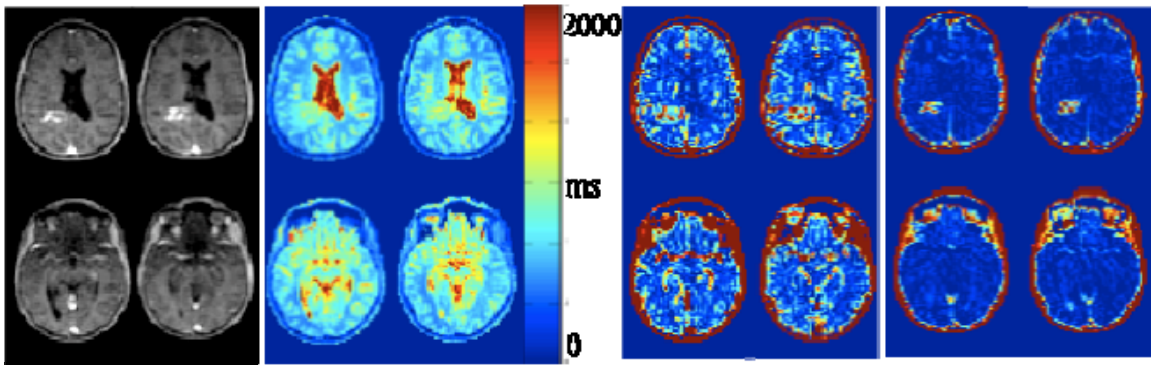

Fig. 2 Representative images of (a) signal intensity (b) T1 (c) Blood volume and (d) Permeability0.

Compared to DESPOT1, the proposed T1 mapping approach simplified signal equations and allowed for faster computation. The effect of B1 inhomogeneity on the estimated values also became apparent.

CONCLUSIONS

CBV and permeability maps with isotropic resolution and whole brain coverage have been obtained clinically with the ME-VIPR sequence in tumor patients. The simplified signal equation at short TRs and low flip angles allows for fast and robust T1 mapping and potentially facilitates the correction of B1 inhomogeneity to improve these measurements.

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