Reducing the scan time in quantitative dynamic contrast enhanced MRI of the breast using the extended graphical model

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Introduction

The Extended Graphical Model (EGM) has the ability to acquire accurate pharmacokinetic parameters (contrast transfer constant: K^{trans}) using a shorter scan time than the widely used modified Kety/Tofts model in dynamic contrast enhanced (DCE) MRI of carotid atherosclerotic plaque [1]. However, in the area of oncology, where DCE MRI and pharmacokinetic modeling are widely used in clinical research, the capability of the EGM has not been investigated. In this study, we sought to evaluate the EGM in breast imaging for use with a novel hybrid DCE MRI that provides separate high spatial and high temporal resolution datasets with full bilateral coverage.

Methods and Materials

Subjects: After informed consent, 8 subjects with invasive breast cancer were included from an ongoing institutional review board approved study using multi-parametric MRI to monitor neoadjuvant chemotherapy. Only the baseline DCE MRI data were used in this study.

MR Imaging Before treatment, all subjects were imaged on a clinical 3T MRI scanner (Philips Achieva TX, Netherlands) using a 16-channel breast coil. The DCE MRI protocol is a fat-suppressed 3D T1-weighted FFE sequence (4D THRIVE) with parallel imaging (SENSE), partial Fourier (half-scan), and elliptical centric k-space acquisition (Fig. 1). The sequence incorporated three high spatial resolution phases of 90s each with 17 interleaved high temporal resolution dynamic phases of 15-30s each before and after contrast (0.1mmol/kg Gd at 2ml/s followed by 20ml saline flush). High spatial resolution imaging parameters: TR/TE = 5.3/2.7ms, SPAIR fat suppression, spatial resolution = 0.6x0.6x2mm (reconstructed to 0.5x0.5x1mm).

High temporal resolution imaging (30s full k-space, 15s using 50% keyhole sampling) parameters: TR/TE = 3.7/1.9ms, SPAIR fat suppression, acquired spatial resolution = 1x1x2mm (reconstructed to 0.8x0.8x1mm).

Fig 1. The DCE-MRI protocol. High spatial resolution acquisitions (90s) are acquired before contrast injection and at 2 min, 6.5 min after contrast injection. High temporal resolution acquisitions (15s/30s) are performed in between.

Image Analysis All images were analyzed using a custom program written in MATLAB (MathWorks Inc.). First, a rough ROI were manually selected to cover the tumor region. By assuming a pre-contrast T1 of 1330ms [2], the contrast concentration curve (Ct) was calculated for each pixel [3]. The arterial input function (AIF) was assumed [4]: $C_p(t) = Ate^{-ta} + B(e^{-tb} + e^{-ta})$, where Cp is the AIF, A=37.15, a=3.90, B=1.52, b=-0.01. Then, the widely used modified Kety/Tofts model [5] was used to calculate a transfer constant (K^{trans}) map of the ROI with all the dynamics (17 dynamics, post-contrast scan time: 390s):

$$C_t(t) = v_p C_p(t) + K^{trans}\int_0^t C_p(\tau) e^{\frac{K^{trans}}{v_e}(t-\tau)} d\tau ,$$

Where, v_p is the partial volume of plasma and v_e the partial volume of extravascular extracellular space. A linearized version of this model was used in model fitting [6]:

$$C_t(t) = v_p C_p(t) + K^{trans}(1+\frac{v_p}{v_e})\int_0^t C_p(\tau)d\tau - \frac{K^{trans}}{v_e}\int_0^t C_t(\tau)d\tau$$

We use modified Kety/Tofts model with long scan time as the "truth", because it better presents the physiological kinetics by considering the contrast flux in and out.

The Extended Graphical Model [1] was also used to generate K^{trans} maps using 17, 16, 15, 14, 13, 12, 11, 10 dynamics, respectively, corresponding to post-contrast scan time: 390s, 360s, 330s, 300s, 270s, 240s, 150s, 135s, respectively:

$$C_t(t) = v_p C_p(t) + K^{trans}\int_0^t C_p(\tau)d\tau - \frac{K^{trans2}}{v_e}\int_0^t\int_0^{\tau_1} C_p(\tau_2)d\tau_2 d\tau_1$$

In fitting of these two models, non-negative least square fitting (lsqnonneg function in Matlab (Mathworks Inc.)) was used. Finally, all pixels in the ROI with maximal enhancement greater than 100% were selected and the mean K^{trans} values of those pixels were calculated and reported for each model.

Data Analysis The K^{trans} values generated by the EGM with 8 different post-contrast scan times were compared with values calculated by modified Kety/Tofts model with all 17 dynamics. Inter-Class Correlation (ICC) and paired t-test were used in comparison.

Table 1. The mean K^{trans} values (min^{-1}) of 8 subjects produced by EGM with 8 different post-contrast scan times and the modified Kety/Tofts model with the full scan time. The red rectangle shows the closest result between two models

Model \ Total Scan Time	390s	360s	330s	300s	270s	240s	150s	135s
EGM	0.1744	0.1749	0.1762	0.1769	0.1753	0.1711	0.1535	0.1495
Modified Kety/Tofts	0.1699							

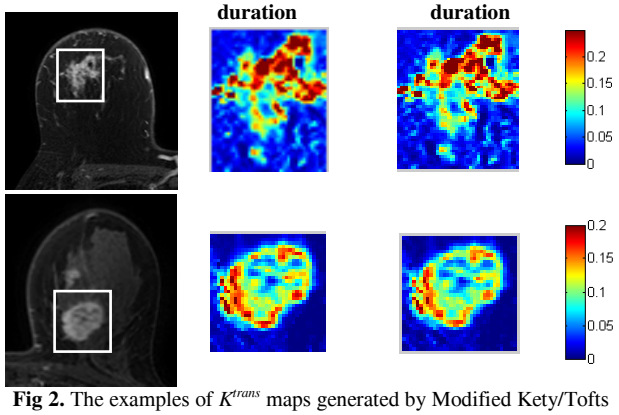

Fig 2. The examples of K^{trans} maps generated by Modified Kety/Tofts model with full duration and EGM with shorter duration. Two rows shows two slices from two cases respectively.

Results

The mean K^{trans} value of 8 subjects calculated with different kinetic models and post-contrast scan times are shown in Table 1. The results of EGM with post-contrast scan time of 240s ($0.1711 min^{-1}$) were found to be closest to the results of modified Kety/Tofts model with post-contrast scan time of 390s ($0.1699 min^{-1}$). The ICC of results generated by EGM (240s) and the modified Kety/Tofts model (390s) were 0.96 ($p<0.001$), and no significant difference were found between them by t-test ($p=0.84$), showing an excellent agreement. Examples of generated K^{trans} maps using these two models (EGM with 240s duration and the modified Kety/Tofts model with 390s duration) are shown in Fig. 2, where good agreement can be seen.

Discussion and Conclusion

This study found that the extended graphical model with shorter post-contrast scan time can produce very similar K^{trans} estimations comparing with the widely used modified Kety/Tofts model in DCE-MRI of breast cancer, indicating that the EGM can reduce the post-contrast scan time necessary for accurate quantitation. The modified Kety/Tofts model with long scan time better presents the physiological kinetics of contrast because it fully models the contrast flux in and out. On the other hand, the EGM only partially models the contrast flux out, resulting in a linear equation. Its advantages, including accurate K^{trans} estimation with shorter duration and relative stable fitting result, have been proven in a previous study on simulation and carotid atherosclerotic vessel wall [1]. In this study, for the first time, the advantage of EGM is validated in breast cancer, suggesting that EGM may be useful in diagnosis and treatment evaluation of tumors.

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