Deconvolution-based dynamic contrast enhanced MR imaging of breast tumors for perfusion quantification: a feasibility study

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Introduction:

Dynamic contrast enhanced (DCE) MRI images using standard Gadolinium chelates reflect the vascular as well as the extraction phase of the bolus transit in tumors. It has been shown that in brain tumors, both these phases can be separated after deconvolution of the tracer concentrations with an Arterial Input Function (AIF) (1,2). Until now, the characterization of breast tumors has been accomplished either by semiquantitative analysis (3) or by estimating kinetic parameters based on compartment modeling of concentration-time curves of contrast material in tumors (4).

Our work aims at the validation of DCE MR sequence for the measurement of regional perfusion and permeability in human breast tumors and its application in the differential diagnosis of benign and malignant breast tumors in order to improve the specificity of tumor characterization. In this initial feasibility study in malignant breast tumors the objective was to investigate whether deconvolution of T1-DCE data on a pixel-by-pixel basis leads to reproducible regional parameters. We also investigated the effect of differences in AIF selection on region-of interest based perfusion and extraction parameters.

Materials and Methods:

In vivo perfusion measurements were performed on nine women with histologically proven malignant breast tumors on a 1.5 T scanner (Philips, Intera, The Netherlands). The routine MR mammography protocol which included dynamic contrast enhanced T1-weighted MR (0.1mmol/kg of Gd-DTPA) as well as high-resolution axial 3D T1 GE with fat suppression was first applied. The slice with tumor in the maximum enhancement was located by examining the above sequences, both of which covered the entire breast. 0.1 mmol/kg Gd-DTPA was injected during dynamic single slice Turboflash acquisition (TR 4.9 msec, TE 2.4 msec, flip angle 50°, TI 196 ms, 128x90 matrix reconstructed at 256x256, FOV 230 x183 mm^2, slice thickness 6 mm, 400 images with a temporal resolution of 0.3s) at that slice position. Image post-processing was performed on a personal computer using software written in-house in IDL. Two AIFs were selected manually, one in the aorta and the other in the ipsilateral internal mammary artery. The signals were first converted to tracer concentrations (5) and the tracer concentration time courses were then deconvolved pixel-by-pixel, using standard-form Tikhonov regularization and an optimized minimization scheme for the L-curve criterion (6). The following parameters were derived from the Impulse Response Function (IRF) at pixel level: tumor blood flow (TBF) measured as the maximum of the IRF, tumor volume of distribution (TVD) measured as the time integral of the IRF and mean transit time (MTT) calculated as the ratio TVD/TBF. IRF for tumor pixels does not drop to zero but forms a slowly decreasing plateau after the vascular peak. This is a typical marker of tracer extraction and may be useful for further tumor characterization, based on vessel permeability. The initial height of the plateau in the IRF curve is a measure for extraction flow product (E.F), calculated as the product of TBF and extraction fraction (E).

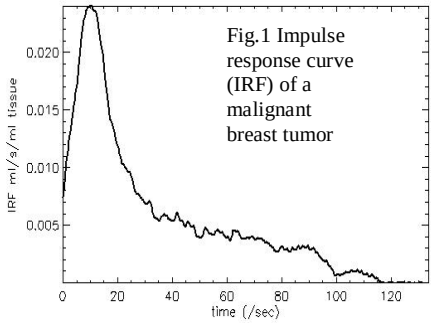

Fig.1 Impulse response curve (IRF) of a malignant breast tumor

Results:

Figure 1 illustrates a typical curve for the deconvolved time course of a malignant breast tumor with vascular peak and plateau. Fig.2 shows the parametric maps of TBF, TVD, MTT and E.F from the same a patient. In all the cases, the parametric maps obviously differentiated tumor from the surrounding breast tissue. Moreover, these maps enabled clear visualization of the heterogeneity within the tumors. A typical mismatch between the parametric maps is noted, which suggests that the results are sufficiently sensitive to identify small regions with different tissue characteristics within the tumor. Our work shows that the choice of the AIF selection drastically affects TBF and TVD, but mostly has a negligible effect on MTT and E.F.

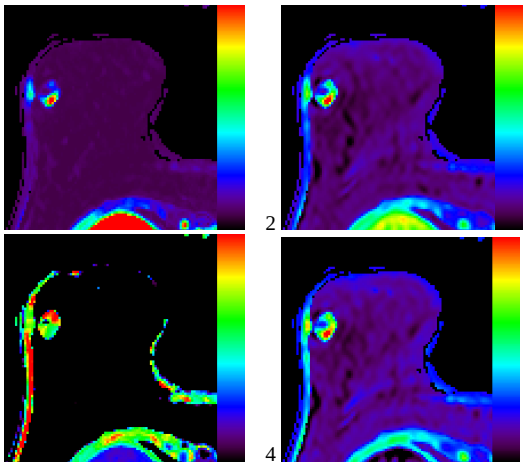

Fig.2: Parametric maps of (1) TBF, (2) TVD, (3) MTT and (4) E.F in a 74-year -old woman with a malignant focus in the right breast. The patient had undergone quadrantectomy of the left breast for breast cancer 5 years back. The tumor focus clearly reveals increased blood flow and volume compared to normal surrounding breast tissue.

Discussion and conclusion:

Our preliminary results show that a pixel-by-pixel deconvolution analysis of T1 weighted bolus tracking data is feasible in breast tumors providing parametric maps of TBF, TVD, MTT, E.F and E. Images of E.F and E may provide useful measures of tumor vessel permeability. Compared to TBF and TVD parameters, MTT and E.F are largely insensitive to differences in AIF selection. As a further step, the efficacy of this method in the differentiation of benign and malignant breast tumors has to be tested.

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