Kinetic Parameter Estimation Based on Independent Component Analysis of Breast Dynamic Contrast-Enhanced MRI

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Introduction

Breast cancer is the second leading cause of cancer deaths among women today. Dynamic contrast-enhanced (DCE) MRI is presently the best strategy for differentiating between benign and malignant breast lesions [1]. DCE-MRI study generates large-volume datasets that are usually time-consuming for radiologists to diagnose, and computer aided diagnosis (CAD) systems are being developed to expedite diagnostic and screening activities. Most CAD systems however, only provide a qualitative view of the temporal characteristics of a given pixel or region of interest (ROI). Such ROI analysis can be very subjective and can lead to variability in interpretation among radiologists. We recently presented our work that demonstrated the effectiveness of independent component analysis (ICA) in extracting the relevant spatial components from DCE-MRI data and its ability to differentiate between benign and malignant tissue [2]. Here we present our initial results on kinetic parameter estimation using the spatial patterns of the ICA output by retrospective evaluation of patient data and compare the results with the radiologist's findings.

Method

Institutional IRB was obtained for this retrospective study. Breast DCE-MRI data on twenty patients were obtained from the research database. All images were obtained using a Siemens 3T Tim-Trio MR system. DCE-MRI acquisition included T1-weighted 3D-FLASH images with imaging parameters TR = 4 ms, TE = 1.68 ms, FOV = 380×380 mm, matrix size = 340×340, and slice thickness = 1.25 mm. Each 3-D volume had a set of 160-176 slices images with the first volume obtained prior to contrast administration followed by another six sets obtained after contrast administration. The mean age of the twenty patients was 57 ± 9 years with a range, 48-62 years. Of the twenty patients, five patients were diagnosed with carcinomas (biopsy confirmed) and fifteen had benign lesions.

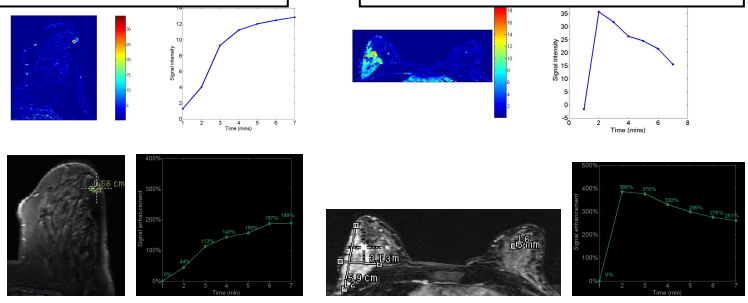
Spatial ICA procedure using Infomax algorithm [3] was applied on breast DCE-MRI datasets following preprocessing which included dimension reduction and whitening. The first three spatial components obtained from ICA processing were further used for kinetic analysis. The raw dynamic pattern provided by the identified region shown in the independent spatial map was utilized for the calculation of kinetic parameters. Kinetic analysis was performed using Buckley's model [4] and curves were fitted to $C_e(t) = \frac{A}{a-b}(e^{-bt} - e^{-at})$, where $A = Dk_{pe}/V_e$, $a = k_{ep}$ and $b = k_{out} + k_{pe}$, in which D ($mmole \cdot g^{-1}$ body weight) is the contrast agent dose, k_{ep}, k_{pe} and k_{out} (min^{-1}) are the rate constants of contrast agents transportation between the blood plasma and extravascular extracellular space compartments as well as depletion by the kidney respectively. It has been shown that parameter A is a function of patient physiologic parameters and MRI imaging parameters, which approximately corresponds to tissue permeability [5]. In a curve fitting routine, a large value of parameter A is usually related to a high initial uptake rate of dynamic pattern and is related to the volume transfer constant K_{trans} through relationship $A = DV_t K_{trans}/V_p V_e$, where V_t, V_p and V_e (ml) represent the volumes of total tissue, blood plasma and extracellular extravascular space respectively. Student t-tests were performed on A to evaluate the differences between ICA assisted pharmacokinetic analysis and radiologists' final diagnosis.

Results

ICA correctly identified all the benign lesions and detected four out of five malignant lesions. The one that was missed was classified as type I by ICA whereas the CAD assisted radiologist's interpretation was type II. Curve types were determined based on the principle proposed by Kuhl et al [1]. Data from two patients are shown in Figure 1, 2 corresponding to a benign and malignant lesion respectively. When the lesions were separated into malignant and benign groups as determined by either ICA or the radiologist, a significant difference between the kinetic parameters was found ($p = 2.51e\text{-}06$ for ICA, and $p=2.76e\text{-}04$ for radiologist) between the benign and malignant lesions. Further, we found no significant difference in the kinetic parameters of the lesions (whether benign or malignant) detected by ICA and those of the radiologist based on their ROI assessment ($p=0.618$). The estimated parameters based on the diagnosis made by radiologists were $A_{malignant} = 7.93 \pm 0.05$ and $A_{benign} = 2.17 \pm 0.03$; the decisions made by ICA yield $A_{malignant} = 9.41 \pm 0.06$ and $A_{benign} = 2.16 \pm 0.03$ ($mmol/(min \cdot ml)$). Receiver operator characteristic analysis showed a sensitivity of 80% for diagnosis made using ICA derived kinetic parameters and a specificity of 100%. Positive predictive value was100% and negative predictive value was 93.8%.

Figure 1 Example of a benign lesion

Figure 2 Example of a malignant lesion



Upper row: **ICA** findings; lower row: **Radiologists'** findings.

Conclusion

Kinetic analysis of ICA derived spatial components has the potential of providing an accurate assessment of the lesions that is comparable to radiologist's findings. While a large study is required to further confirm this finding, automation detection of breast lesions with further classification of the kinetic parameters of the detected lesions can have very positive workflow implications for the radiologists. Further, quantitative information from such a system can aid in the longitudinal follow-up of patients.

References

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