Morphometry of Intratumoral Enhancement Patterns on 4D Spectral Images for Differential Diagnosis of Breast Tumors in Dynamic Contrast-enhanced MRI

S. Lee[1,2], J. Kim[2,3], I. Song[2,3], Y. Jung[1,2], J. Park[4], and W. Moon[3]

[1]Interdisciplinary Program in Radiation Applied Life Science, Seoul National University College of Medicine, Seoul, Korea, Republic of, [2]Institute of Radiation Medicine, Seoul National University Medical Research Center, Seoul, Korea, Republic of, [3]Department of Radiology, Seoul National University College of Medicine, Seoul, Korea, Republic of, [4]Department of Radiology, Hanyang University College of Medicine, Seoul, Korea, Republic of

Introduction

The characterization of intratumoral enhancement patterns in dynamic contrast enhanced (DCE) MRI is important for the non-invasive diagnosis of breast tumors, and yet remains challenging due to the spatio-temporal complexities in the tumor uptake and clearance kinetics of contrast agents. A recent study has demonstrated the superiority of capturing the spatio-temporal enhancement pattern in accurate tumor characterization for breast MR-based diagnosis [1]. However, there were limitations that its analysis was based on a selected 2D image and tumors were segmented from a manually delineated contour. Here we present an integrated framework for 3D semi-automatic tumor segmentation and characterization of 3D spatio-temporal properties of intratumoral enhancements by using a quantitatively combined approach of tumor kinetics and morphometry. The influence of the combined spatio-temporal enhancement features on the performance is tested for differentiation of benign and malignant tumors in breast DCE-MRI.

Materials and Methods

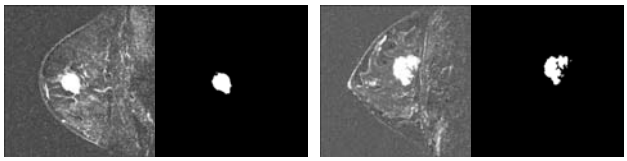
Twenty female patients were recruited to this study and one primary lesion from each patient was used for analysis. DCE MRI was carried out on a 1.5T scanner (Magnetom Sonata; Siemens, Erlangen, Germany) using T1-weighted 3D FLASH sequence: 448×448, TE=1.83 msec, TR=4.9 msec, flip angle=12°, slice thickness=1-1.5 mm without a gap, temporal resolution=84 sec per 96-111slices. One pre-enhanced and four post-enhanced series following a bolus injection of Gd-DTPA (Magnevist, Schering, Berlin, Germany; 0.1 mmol/kg at 2 ml/sec for 5 sec) were acquired as unilateral sagittal images. After 3D rigid registration of MR-time-series, our proposed perfusion index (PI) map was generated for enhanced tumor contrast, which widens the difference of variations in enhancement kinetic features between a lesion and normal parenchyma and allows effective identification of tumors [2]. On the PI map, tumor segmentation was performed by using Otsu thresholding, 3D region growing algorithm, hole-filling and iterative morphological erosion and dilation. Temporal enhancement (TE) features were extracted by singular value decomposition (SVD) of a lower-triangular Toeplitz matrix representing convolution operation, and their SVD-based eigenvalue (EV) maps were generated. The spatial variations of EVs within each tumor were captured by 3D geometric moment invariants (GMIs) [3]. The binary classification for tumor differentiation was performed by Least Square Support Vector Machines (LS-SVM) with a Radial Basis Function (RBF) kernel. Leave-one-out cross-validation was used in the classification process, which was repeated fifty times by iteratively retraining the LS-SVM in order to obtain an average test result. The average test performance was measured by Receiver Operating Characteristic (ROC) curve analysis.

Results

All of the malignant lesions were 10 invasive ductal carcinomas and the histological distributions of the benign lesions were 2 fibroadenomas, 3 papilomas, 3 phylloides tumors, 1 hamartoma and 1 atypical hyperplasia. The PI map successfully identified the margins of tumors in most instances and the segmentation results showed good agreement with tumor boundaries. A total of twenty-four SVD-based GMI features were extracted from each tumor to represent the spatio-temporal properties within the tumor. In an evaluation experiment with 10 malignant and 10 benign cases, the average test performance showed the area under ROC curve (AUC) of 0.795 (95% confidence interval, 0.768-0.819) with sensitivity and specificity of 96.4% (95% confidence interval, 94.4-97.9%) and 75.6% (95% confidence interval, 71.5-79.3%), using LS-SVM RBF applied to the SVD-based GMI features.

Conclusion

With this pilot study for MR-based computer-aided diagnosis (CAD) of breast tumors, we have shown that: (1) 3D tumor segmentation problem of breast tumors in DCE-MRI can be solved effectively in the way that made the best use of tumor perfusion characteristics; (2) Combination of SVD and 3D GMI yields a promising descriptor to characterize and differentiate the spatio-temporal enhancement patterns within tumors in breast DCE-MRI.



(a) (b)

Figure 1. Examples of the PI map (left) and tumor segmentation outcome (right) for (a) malignant (invasive ductal carcinoma) and benign (fibroadenoma) tumors

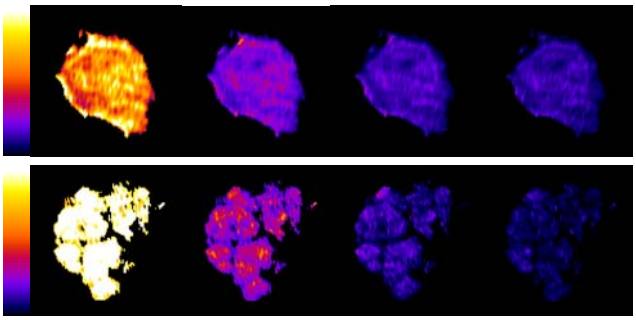


Figure 2. Examples of SVD-based EV maps for malignant (top) and benign (bottom) tumors: the 1st, 2nd, 3rd and 4th EV maps from left to right

References

[1] Y Zheng, S Englander, et al. IEEE ISBI 2007: 520-523.
[2] S Lee, J Kim, et al. IEEE ISBI 2008: 1545-1548.
[3] D Xu, H Li, Pattern Recognition 2008: 41, 240-249.

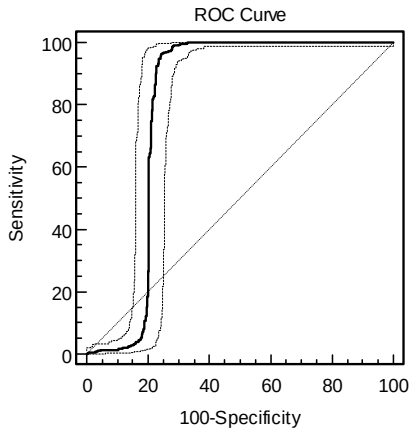


Figure 3. ROC curve of SVD-based GMI features for tumor differentiation (dashed line: 95% confidence limits)