Improving the Diagnostic Accuracy of 3D Breast DCEMRI Data Using an Empirical Mathematical Model

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Introduction: The majority of mathematical models applied to breast DCEMRI require high temporal resolution and protocols that are not clinically feasible[1]. The purpose of this study is to apply an empirical mathematical model (EMM) to kinetic data from breast DCEMRI acquired under a clinical protocol with sparse time resolution, and to determine if the sensitivity and specificity can be improved compared with qualitative BI-RADS descriptors of kinetics.

Methods: 34 benign and 79 malignant lesions were selected for review under an IRB approved protocol. One pre and five post-contrast images were acquired in the coronal plane using 3D T_1-weighted SPGR (TR/TE = 7.7/4.2 msec, flip angle = 30˚, slice thickness = 3 mm, and in plane resolution = 1.4 mm, 68 sec acquisition). The radiologist traced a small region of interest (ROI) around what was perceived to be the most enhancing part of the lesion on the first post-contrast image. The kinetic curve represents the signal intensity in the ROI vs. time. This curve was assessed by the radiologist according to the BI-RADS lexicon for initial rise (rapid, medium, slow) and delayed phase (persistent, plateau, washout). The kinetic curve was also analyzed quantitatively using the EMM: $\Delta S(t) = A \cdot \left(1 - e^{-\alpha t}\right) \cdot e^{-\beta t}$, where A is the upper limit of signal intensity, α is the rate of signal increase (min^{-1}), β is the rate of signal decrease during washout (min^{-1}). Several secondary parameters were also derived from this equation including the initial slope (**$Slope_{ini}$**), curvature at the peak (**κ_{peak}**) and the signal enhancement ratio (**SER_{60}**)[2]. ROC analysis was used to compare the sensitivity and specificity of the model parameters with the BI-RADS descriptors. In addition, the average parameter values were studied for subtypes of malignant lesions: ductal carcinoma in situ (DCIS, n=30), invasive ductal carcinoma (IDC, n=36) and invasive lobular carcinoma (ILC, n=7).

Results: The classification of the initial intensity increase according to BI-RADS did not differ significantly between malignant and benign lesions, but the delayed phase was significantly different, with 65% of malignant lesions and 38% of benign lesions showing washout curves ($p < 0.05$). The BI-RADS delayed phase descriptors had sensitivity and specificity of 91% and 18%, respectively. The EMM was able to accurately fit these curves. There was a statistically significant difference between benign and malignant lesions for the parameters: **α** ($p < 0.03$), **$Slope_{ini}$** ($p < 0.04$), **κ_{peak}** ($p < 0.02$) and **SER_{60}** ($p < 0.0007$) (**Table 1**). The ROC curves for **α** and **SER_{60}** in **Fig. 1** demonstrates improvement in the diagnostic performance compared with the BI-RADS categories—at a sensitivity of 90%, the specificity was 20-30%. The kinetic parameters of DCIS lesions overlapped considerably with many benign lesions, suggesting that diagnostic performance could be improved if only IDC lesions were considered, as is most commonly done elsewhere. To explore this, **Fig. 1** also shows ROC curves for **α** and **SER_{60}** discriminating benign vs. IDC lesions only, which have larger A_z values and demonstrate improved diagnostic accuracy compared to the benign vs. all malignant counterparts.

Discussion: Malignant lesions had a larger uptake rate, larger initial slope, sharper curvature at the peak and stronger washout compared with benign lesions ($p < 0.04$). The specificity reported here is lower than some other reports[3]. This may be because the benign cases studied here required biopsy, and thus were the more suspicious benign lesions with features that may overlap more with malignant lesions—in particular DCIS, which comprised a large proportion of the malignant lesions studied here. Increased time resolution would take better advantage of the EMM and would likely improve the diagnostic accuracy. These results show that analysis of DCEMRI data with the EMM provides at least the diagnostic accuracy of the BI-RADS classifiers, and offers a few key advantages. It can be automated and can provide a more objective classification. It provides continuous variables so that thresholds can be set to achieve desired sensitivity and specificity—for example, at a sensitivity of ~65% the specificity was ~60 %, which is good diagnostic accuracy in a population with suspicious benign lesions. It also offers an opportunity to relate semi-quantitative parameters (such as **SER_{60}**) to more fundamental EMM parameters, allowing comparisons to be made across institutions with different protocols. More importantly, this model allows for more flexibility in improving sensitivity and specificity in the future by using combinations of variables, corrections for arterial input functions and relating parameters directly to underlying physiological quantities. This suggests that the EMM may be useful for analysis of routine clinical data.

	Benign (n=34)	**Malignant (n=79)**
α (min^{-1})	1.6±1.1	2.1±1.1
$Slope_{ini}$ (min^{-1})	6.1±4.6	8.7±8.3
κ_{peak}	-0.30±0.49	-0.67±1.18
SER_{60}	0.88±0.30	1.14±0.48

Table 1: Primary & derived EMM parameters.

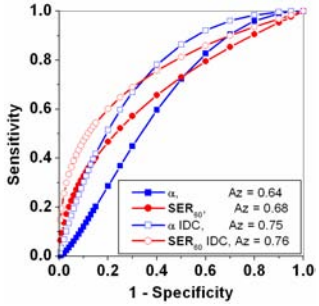

Figure 1: ROC curves for **α** and **SER_{60}**.

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[2]Esserman et al. Breast J. 1999 Jan; 5(1): 13-21.
[3]Kuhl et al. Radiology. 1999 Apr; 211(1):101-10.