Combined MRI texture and shape analysis for the prediction of biologic aggressiveness in musculoskeletal neoplasms

R. E. Thornhill[1], G. O. Cron[1], I. Cameron[1], A. Sheikh[1], G. Di Primio[1], J. Werier[1], M. E. Schweitzer[1], J. Zhang[2], and X. G. Cheng[2]
[1]The Ottawa Hospital, Ottawa, Ontario, Canada, [2]Beijing Ji Shui Tan Hospital, Beijing, China, People's Republic of

INTRODUCTION: Musculoskeletal (MSK) tumors are uncommon but usually afflict young adults and thus result in considerable debility [1,2]. At initial presentation, current MRI techniques are often unable to distinguish malignant from benign masses. This has motivated the development of more advanced, quantitative MRI techniques such as dynamic contrast-enhanced (DCE-) MRI [3]. Tracer kinetic parameters such as the transendothelial transfer constant (K^{trans}) derived from DCE-MRI have been convincingly associated with tumor aggressiveness in many non-MSK malignancies [4], but the relative rarity of MSK tumors has limited published DCE-MRI studies to a small number of reports [5-7]. Furthermore, the results of DCE-MRI studies are conventionally reported in terms of the mean K^{trans} for an entire tumor [8], which neglects potentially important information regarding the spatial distribution ('texture') and the morphology ('shape') of K^{trans} abnormalities or tumor 'hot spots.' We hypothesized that textural and shape features extracted from DCE-MRI K^{trans} maps will delineate benign from malignant MSK tumors more accurately than either texture or shape analysis used in isolation.

MATERIALS AND METHODS: n=86 patients aged 5-76 y (median 29 y; 65 men and 21 women) were examined at 1.5T with an IR-prepared GRE DCE protocol (General Electric, Milwaukee, USA) with: 288 x 160, 16 slices, 6 mm slice thickness, 21 ms TI, 6.3 ms TR, 1.56 ms TE, 20º flip, 20 s temporal resolution, total scan time 4 min. Gd-based contrast was injected as a bolus (0.1 mmol/kg) following initiation of the GRE sequence. Histopathological grade and subtype of each tumor were subsequently confirmed by either core or open (surgical) biopsy. DCE datasets were motion-corrected by an automatic sub-pixel registration algorithm implemented in ImageJ (http://rsbweb.nih.gov) [9]. Standard equations converted tissue signal intensity vs. time curves to contrast-concentration vs. time, [C](t). It was necessary to estimate the pre-contrast T1 of the tumors by referencing their signal to muscle (T1 of muscle assumed to be 1000 ms), and a population AIF was necessary due to the low temporal resolution [10]. Voxel-by-voxel K^{trans} maps were constructed for each patient [11] and tumor regions of interest (ROIs) were defined by an experienced MSK radiologist. Feature computation: All textural and shape features were computed using MaZda version 4.6 (P.M. Szczypiński, Institute of Electronics, Technical University of Lodz, Poland). *Texture:* 70 textural features were evaluated [12]. In addition to first-order K^{trans} histogram features, we also extracted second-order statistical features. Self-similarity and multi-scale K^{trans} patterns were assessed by autoregressive model and wavelet transform features, respectively [12]. *Shape:* 73 features were derived based on the defined ROI morphologies. In addition to measuring the lengths, widths, and perimeters of the tumor ROI, we also computed shape features based on the inscribed circle, ellipse and rectangle. These simple geometrical parameters were used to derive other descriptors such as roundness, circularity, and eccentricity of the tumor ROI [13]. The remaining features were determined by finding the medial axes and branch-points of the tumor. Feature selection: We reduced the dimensionality of our feature space from 143 to 18 on the basis of the Fisher coefficient of each feature. Classification: linear discriminant analysis (LDA) was used to reduce the feature space to its 'most discriminative features' (MDF) [14]. MDF distributions corresponding to (true) benign and malignant tumors were used to generate receiver operator characteristic (ROC) curves.

RESULTS: 48 tumors were malignant, 38 benign. Representative K^{trans} maps produced from DCE-MRI of benign and malignant MSK tumors are provided in Figure 1. The distribution of MDF for shape, texture, and combined shape and texture feature sets for benign and malignant tumors are shown in Figure 2(a). ROC curves for shape, texture, and combined shape and texture analysis (Figure 2(b)) indicate superior sensitivity, specificity, and accuracy for the combined approach (75%, 79%, and 77%, respectively).

DISCUSSION: The results of this retrospective study suggest that a combined texture and shape analysis of DCE-MRI can delineate malignant from benign MSK tumors with a promising degree of accuracy. While texture analysis can provide an objective means of quantifying the spatial complexity and heterogeneity of tumor K^{trans}, shape descriptors provide us with a quantitative means of distinguishing the rounded margins of benign tumors from the spiculated or ill-defined margins of most malignancies. Together, texture and shape analysis of DCE-MRI may provide robust and accurate characterization of MSK tumors. However, future studies should capitalize on improved DCE temporal resolution and the use of phase information [15].

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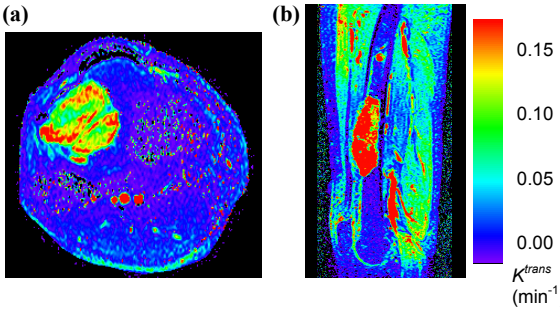

FIGURE 1: K^{trans} maps produced from DCE-MRI of (a) 31-year-old male with a giant cell tumour, and (b) 59-year-old female, metastasis.

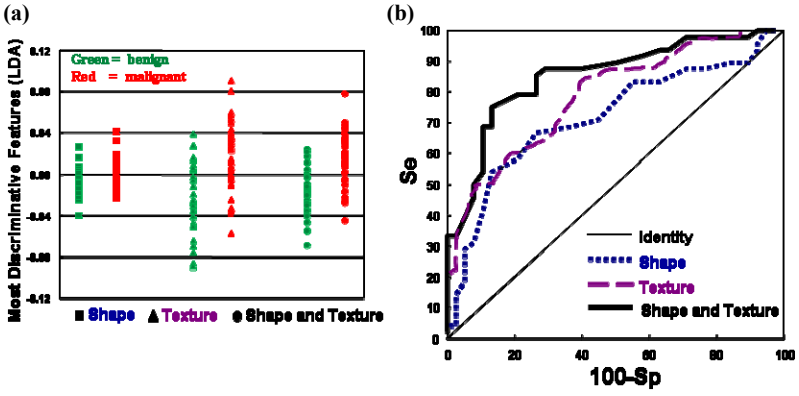

FIGURE 2: (a) scatter plots depicting benign vs. malignant tumor shape (squares), texture (triangles), and combined shape + texture K^{trans} map characteristics (circles). (b) ROC curves for shape analysis (dotted line), texture analysis (dashes), and shape + texture analysis (solid).