Dynamic Contrast-enhanced MRI for Detection of Bone Metastases from Prostate Carcinoma: a Study of Kinetic Parameter with Reference Local Voxel Cluster Model

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Purpose:

To evaluate bone metastases (BM) from prostate cancer by using kinetic parameters of dynamic contrast enhanced MR imaging from the proposed reference local voxel cluster (RLVC) model.

Materials and Methods :

Fourteen patients, pathologically proved of prostate cancer, were recruited in this study. Totally, 41 bone metastatic lesions were determined by imaging and clinical evaluation. All patients underwent MR examination, including T1 weighted imaging, T2 weighted imaging, diffusion weighted imaging (DWI), and dynamic contrast-enhanced (DCE) imaging. DCE-MRI quantitative parameters (including rate constant for passive contrast reagent transfer between plasma and interstitium (K_{trans}) and interstitial space volume fraction v_e) of the metastatic lesion, normal bone, and pelvic muscle were extracted by RLVC, expressed as formula (1).

$$\arg\min_{x_{i,j}} \sum_{\substack{m=i,n=j \\ m=i+1,n=j \\ m=i,n=j+1 \\ m=i+1,n=j+1}} \sum_{i=i_1}^{i_{N-1}} \left(\frac{1}{K_{trans}^{m,n}} \cdot \frac{d}{dt} C_t^{m,n}(t) + \frac{1}{v_e^{m,n}} \cdot C_t^{m,n}(t) - C_p^{i,j}(t) \right)^2 +$$

$$\alpha \sum_{\substack{m=i+1,n=j \\ m=i,j=j+1}} \left((\frac{1}{K_{trans}^{i,j}} - \frac{1}{K_{trans}^{m,n}})^2 + (\frac{1}{v_e^{i,j}} - \frac{1}{v_e^{m,n}})^2 + (\frac{1}{K_{trans}^{i+1,j+1}} - \frac{1}{K_{trans}^{m,n}})^2 + (\frac{1}{v_e^{i+1,j+1}} - \frac{1}{v_e^{m,n}})^2 \right) \quad (1)$$

The kinetic parameters of metastatic bones and normal bones were compared, with independent T-test. Paired T-test was used to compare the metastatic area between the K_{trans} Map and DWI.

Results:

All lesions are detected by RLVC based K_{trans} Map (100%) while a total of 38 lesions are detected by DWI(92.6%) from the 41 bone metastatic lesions. It was demonstrated in Fig. 1 that the kinetic parameters of BM are significantly higher than those of normal bones (metastatic foci K_{trans} 0.101±0.029 min^{-1} and v_e 0.595±0.117; normal bones K_{trans} 0.017±0.009min^{-1} and v_e 0.411±0.065). The average area (Fig. 2,3)of the 41 metastatic lesions (929.93 mm^2) in the K_{trans} Map is significantly larger than that (425.32 mm^2) of DWI (P<0.001).

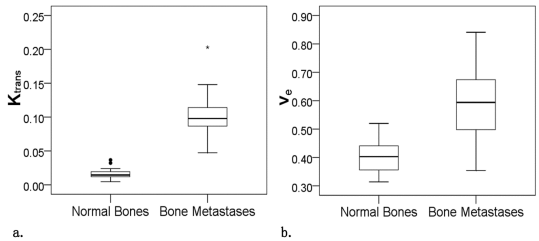

FIG. 1. Box-and-whisker plots show (a) K^{trans} (b) v_e, calculated respectively for normal bones and BM (P <0.001). Symbols above plots in Fig 1(a) are outliers.

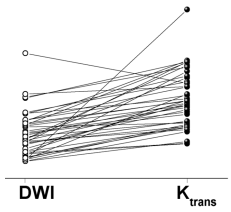

FIG. 2. Dot-line diagram of area of abnormal region with BM detected by K_{trans} and DWI. ●= area values of abnormal region with BM detected by K_{trans}. ○= area values of suspected region with BM detected by DWI. The average area of abnormal region with BM detected by K_{trans} is significantly larger than that by DWI (P <0.001).

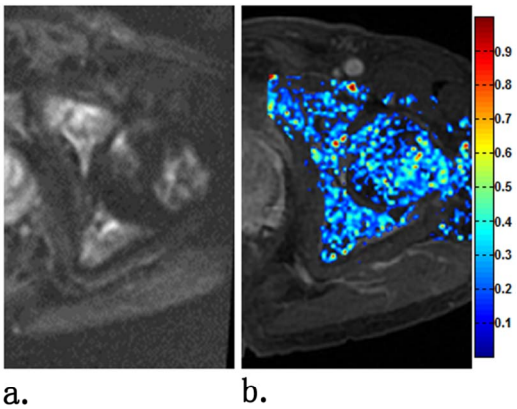

FIG. 3. Pelvis MR of 51-year-old man with prostate cancer (PSA level 2150ng/ml, Gleason Score 5+5=10). The BM lesion of the left acetabular bone and femur head demonstrated high signal intensity on the DW images (a). The size of BM lesion in the K_{trans} map (b) shows 787 mm^2 in posterior left acetabular bone and 766 mm^2 in anterior left acetabular bone) are slightly larger than that in the DWI (a) image (436 mm^2 and 740 mm^2). The size of BM lesion in the K_{trans} map (b) shows 1399 mm^2 in left femur head is significantly larger than that in the DWI (a) image (322 mm^2).

Conclusions:

Results suggest that the kinetic parameters (K_{trans}, v_e) extracted from the proposed RLVC model are effective, and compared to the corresponding DWI image, K_{trans} map exhibit larger abnormal area, indicating its higher sensitivity for metastases. It is closely associated with the processes of cancer metastasis that tumors must induce the formation of neovasculture if they are to grow beyond minimal size [1]. While DWI mainly depicts water mobility determined by the interaction of water with intracellular elements, macromolecules, cell membranes, cell density, and microstructural organization [2], K_{trans} can reveal the tissue permeability and perfusion property caused by arterial blood vessels proliferation, and determined by the abundance and transfer rate of vessels in region of interest. Disease processes that alter the characteristics of cells, including cell-water homeostasis, cell density, and cytoarchitecture affect water mobility, and by the conventional T1WI, T2WI and DWI (high b value), the change of those characteristics can only be found out when the tumor foci contains enough cancerous cells. In contrast, hypervasculature, which can be detected by the $K_{trans,}$ plays a major role, such as supplying essentials in the early stage of bone tumor infiltration from prostate carcinoma. Thus it is believed that the RLVC model could provide a valuable tool for the potential detection of early bone metastasis.

References:

[1]Dvorak HF, et al. J Surg Oncol. 2011; 103:468–474. [2] Mori S, et al. Anat Rec. 1999; 257:102–109.