Optical model mapping for characterizing tumor microcirculation with diffusion weighted imaging in head and neck cancer

Yonggang Lu¹, Jacobus F.A. Jansen², Yousef Mazaheri¹, Hilda Stambuk³, and Amita Shukla-Dave¹ ¹Medical Physics Department, Memorial Sloan-kettering Cancer Center, New York, NY, United States, ²Radiology Department, Maastricht, University, Maastricht, Maastricht, Netherlands, ³Radiology Department, Memorial Sloan-kettering Cancer Center, New York, NY, United States

Introduction

Intravoxel incoherent motion diffusion-weighted magnetic resonance imaging (IVIM MRI) holds the promise of characterizing tumor microcirculation which consists of water diffusion and blood perfusion¹. Since tumor tissue is heterogeneous in nature, single model cannot quantify the complex microcirculation comprehensively and may generate deviated parametric estimations. In this study, we propose to develop optimal model mapping method to characterize head and neck tumor microcirculation. It is hypothesized that the parametric values quantified from the optimal models will characterize tumor microcirculation more accurately and the generated optimal model map will better display the underlying tumor heterogeneity.

Methods

<u>*MRI* data acquisition</u>: Twelve head and neck cancer patients with neck nodal metastases were enrolled in this retrospective study which was approved by local institutional review board (age: 43-67 years, M/F: 9/3, and primary cancer: 3 nasopharynx and 9 oropharynx). All patients underwent diffusion weighted imaging (DWI) study on a GE 1.5T Excite scanner with an 8-channel neurovascular phased-array coil. A single-shot echo planar imaging (SSEPI) spin echo sequence was used for DWI with b values (b=0, 10, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 300, 500, 700, 900, 1100, 1300, 1500 s/mm²). Other acquisition parameters were: field of view = 20-26mm, slices= 4-6, thickness = 4-8mm depending on the tumor size, TR = 3000 ms, TE= minimum, NEX=4, matrix=128 x 128.

<u>Optimal model mapping (OMM)</u>: Four published models (IVIM¹, NG-IVIM², Kurtosis³, and ADC¹) were used for optimal model determination at each voxel within the metastatic node in patients with head and neck cancer (Fig.1). For each voxel, the optimal model was determined using the Bayesian Information Criterion (BIC=N_b×ln(χ^2/N_b)+ N_p×ln(N_b))², where χ^2 was the sum of squared error between observed and expected data, N_b is the sample size and N_p is the number of free parameters to be estimated (N_p = 5 for the NG-IVIM model, N_p = 4 for the IVIM model, N_p = 3 for the Kurtosis model and N_p = 2 for the ADC model in this study). Measures (f-vascular fraction, D-diffusion coefficient, D*-pseudo-diffusion coefficient, K-diffusion kurtosis, ADC- apparent diffusion coefficient) were characterized on a voxel-by-voxel basis. The voxel percentage preferred by each model was then calculated and the optimal model map was generated.

Results

Fig. 1 shows the result of optimal model determination for a typical voxel with a representative patient. The optimal model for the voxel denoted by the red arrow was determined as the NG-IVIM model since the fitting by the NG-IVIM model for the voxel has minimum BIC value compared to other three models. Fig.2 displays optimal model maps for the other 11 patients. For 12 patients, the range of voxel percentages preferred by each model were: 2.3% to 79.3% for the NG-IVIM model, 17.3% to 97.7% for the IVIM model, 0% to 21.3% for the Kurtosis model, and 0% to 56.1% for the ADC model, as shown in Table 1.

Discussion and Conclusion

The results demonstrated that the IVIM and NG-IVIM model were the main methods to model DW-MRI signal decay of tumor tissues, suggesting most of the tumor tissue voxels exhibited both perfusion and water diffusion. The generated optimal model maps in 12 head and neck cancer patients clearly describe the locations of preferred model at each voxel within the tumor tissues, showing

underlying tumor heterogeneity in either an intra-tumor or inter-tumor fashion. The optimal maps and associated voxel percentage for each model may hold promise to describe and quantify tumor heterogeneity. In the future, we will test whether this method can be used into the investigation of tumor diagnosis, staging and treatment monitoring in head and neck cancers.

Acknowledgments

Supported by NCI/NIH grant (1 R01 CA115895).

References

[1] Le Bihan D et al., Radiology 1988;168(2):497-505. [2] Lu Y et al., JMRI 2012; 36(5):1088-96. [3] Jensen JH et al., MRM 2005;53(6):1432-1440.



Fig.1 Data fits for a metastatic neck node in a representative patient (patient no. 2 in Table 1) using different models. (a) The metastatic node on the DW-MR image at b=0 s/mm². (b) The optimal model map for the metastatic node. (c) Data fits using different models at a typical voxel, which is marked by a red arrow in (b). (d) The zoomed plot of (c) at low b values. (e) Bar plots of χ^2 and BIC for each model at the typical point. In (c) and (d), the vertical axis represents the logarithmic of S/S_b=0 (S_b=0 is the DW-MR image intensity at b=0) for DW-MR I signal and $\sigma/S_b=0$ for noise (σ is the estimated standard deviation of noise).



Fig.2 The generated optimal model maps from head and neck cancer patients (patient no.1, 3-12). The region of interest was the metastatic neck node. Note: Data from patient no. 2 is shown in Figure 1.

| Table 1 | Voxel | percentages | preferred by | each model | from 12 | head and | neck cancer | patients |
|----------|--------|-------------|--------------|------------|----------|----------|-------------|----------|
| rable r. | 1 OACI | percentages | preferred by | cach mouch | 11011112 | meau anu | neek cuncer | patiento |

| Patient | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|----------|------|------|------|------|------|------|------|------|------|------|------|------|
| Models | | | | | | | | | | | | |
| NG-IVIM | 2.3 | 23.6 | 64.2 | 47.5 | 79.3 | 6.4 | 5.7 | 19.0 | 3.2 | 10.6 | 6.8 | 12.3 |
| IVIM | 97.7 | 76.4 | 34.8 | 48.2 | 17.3 | 77.7 | 76.5 | 80.0 | 43.5 | 69.2 | 34.5 | 56.4 |
| Kurtosis | 0 | 0 | 1.0 | 1.2 | 0 | 0.2 | 1.7 | 1.0 | 21.3 | 2.8 | 2.6 | 3.5 |
| ADC | 0 | 0 | 0 | 3.1 | 0 | 15.7 | 16.1 | 0 | 32.0 | 17.4 | 56.1 | 27.2 |