Triexponential function analysis on diffusion-weighted MRI in diagnosing prostate cancer

Yu Ueda[1], Satoru Takahashi[2], Naoki Ohno[3], Katsusuke Kyotani[1], Nobukazu Aoyama[1], Hideaki Kawamitsu[1], Yoshiko Ueno[2], Kazuhiro Kitajima[2], Fumi Kawakami[4], Tomoyuki Okuaki[5], Toshiaki Miyati[3], and Kazuro Sugimura[2]

[1]Division of Radiology, Kobe University Hospital, Kobe, Hyogo, Japan, [2]Department of Radiology, Kobe University Hospital, Kobe, Hyogo, Japan, [3]Faculty of Health Sciences, Institute of Medical, Pharmaceutical, and Health Sciences, Kanazawa University, Kanazawa, Ishikawa, Japan, [4]Department of Diagnostic Pathology, Kobe University Hospital, Kobe, Hyogo, Japan, [5]Philips Healthcare Asia Pacific, Minato-ku, Tokyo, Japan

Introduction:

Intravoxel incoherent motion (IVIM) model has been reported to separate extravascular molecular diffusion and microcirculation of blood within the capillaries (perfusion) with a biexponential decay utilizing low b-values [1, 2]. At high b-values, on the other hands, a biexponential analysis differentiates between fast and slow diffusion component, which could represent extracellular free diffusion and intracellular restricted diffusion, respectively [3, 4]. Thus, using both low and high b-values, it is expected that triexponential function analysis would reveal three diffusion components in biological tissue. Tissue perfusion has been evaluated with dynamic contrast enhanced (DCE)-MRI applying pharmacokinetic analysis and intra- and extracellular components can be assessed only with histopathological specimens. The objective of our study is to evaluate the clinical usefulness of triexponential function analysis of diffusion-weighted MRI for the prostate cancer in the peripheral zone (PZ) with reference to the histopathological findings and pharmacokinetic parameters on DCE-MRI.

		PZ cancer (n=24)	normal PZ (n=24)	*P*
Triexponential analysis	D_p (x10^{-3}mm^2/s)	28.7±17.8	17.0±10.7	†
	D_f (x10^{-3}mm^2/s)	2.89±0.47	2.98±0.19	n.s.
	D_s (x10^{-3}mm^2/s)	0.46±0.08	0.70±0.09	† †
	F_p (%)	5.92±3.31	3.94±2.14	†
	F_f (%)	40.5±7.29	64.5±6.71	† †
	F_s (%)	53.6±8.11	31.6±6.86	† †
Biexponential analysis	D^* (x10^{-3}mm^2/s)	7.26±2.16	7.90±2.38	n.s.
	D (x10^{-3}mm^2/s)	0.69±0.14	1.47±0.26	† †
	F (%)	25.6±5.16	21.2±3.41	† †
Monoexponential analysis	ADC (x10^{-3}mm^2/s)	0.93±0.23	1.83±0.26	† †

n.s.=not significant, †: p<0.05, † †: p<0.01

Table 1. Each derived parameter of PZ cancer and normal PZ

Materials and Methods:

This study was approved by the institutional review board (IRB) and was performed only after informed consent was obtained from each patient. 24 patients (mean age, 64.0±6.58 years) with biopsy-proven prostate PZ cancer underwent preoperative prostate MRI at 3.0-T unit including multiple b-values DWI with 8 steps of b-values of 0, 50, 100, 200, 500, 1000, 2000, and 3000s/mm^2. Regions of interest (ROIs) were placed to analyze triexponential function for cancerous and non-cancerous lesion by referencing histopathological results. A contralateral PZ in PZ cancer was served as normal. Triexponential function analysis was performed to derive perfusion-related, fast free, and slow restricted diffusion coefficients (D_p, D_f, D_s), as well as fractions (F_p, F_f, F_s). Moreover, the results of triexponential function analysis were compared to those of bi- and monoexponential function analyses. Each diffusion parameter for normal PZ and cancerous lesions was compared by Wilcoxon signed-rank test. The ratio of extra- and intracellular component for cancerous lesions measured with the histopathological specimens and K^{trans} and V_e calculated with DCE-MRI were compared to diffusion parameters using the Pearson correlation.

Results:

All diffusion parameters obtained are summarized on Table 1. D_p was significantly greater in cancerous lesions than normal PZ ($P < 0.05$), and D_s was significantly smaller in cancerous lesions ($P < 0.01$). There was no significant difference in D_f between cancerous lesions and normal PZ ($P = 0.35$). D_p showed significant correlation to K^{trans} (Fig. 1), while F_f was significantly correlated with V_e (Fig. 2). F_s was significantly correlated with intracellular space fraction evaluated with histopathological specimens (Fig. 3).

Conclusion:

Triexponential analysis can provide more detailed information on perfusion and diffusion of prostate cancer noninvasively, and makes it possible to assist in the diagnosis of prostate PZ cancer. Moreover, our findings suggested that the reduction of ADC in PZ cancer would be due to the decrease of D_s that reflects intracellular restricted diffusion.

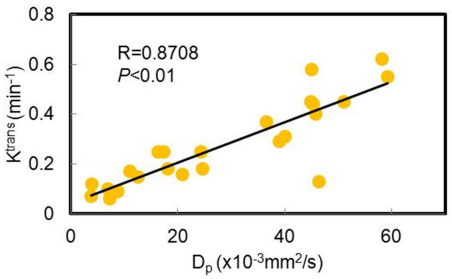

Figure 1. Relationship between D_p and K^{trans}

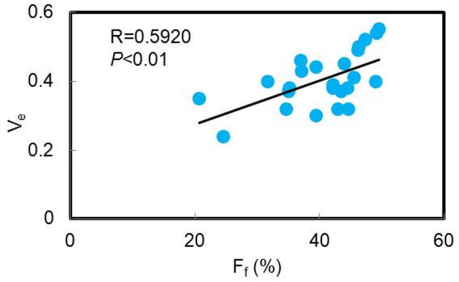

Figure 2. Relationship between F_f and V_e

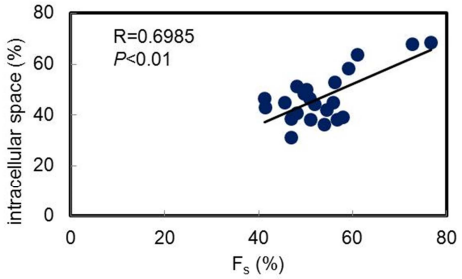

Figure 3. Relationship between F_s and intracellular space obtained from pathological specimens

Reference:

[1] Le Bihan D et al, Radiology 1988: 168: 497-505.
[2] Shinmoto H et al, AJR Am J Roentgenol 2012: 199: 496-500.
[3] Mulkern RV et al, Magn Reson Imaging 2006: 24: 563-568.
[4] Shinmoto H et al, Magn Reson Imaging 2009: 27: 355-359.