# Diffusion-weighted imaging of prostate cancer using statistical model based on a gamma distribution

Hiroshi Shinmoto[1], Chiharu Tamura[1], Shigeyoshi Soga[1], Teppei Okamura[1], Kentaro Yamada[1], Tatsumi Kaji[1], and Koichi Oshio[2]
[1]*Radiology, National Defense Medical College, Saitama, Japan,* [2]*Diagnostic Radiology, Keio University, School of Medicine, Tokyo, Japan*

**Introduction:**

Diffusion-weighted imaging (DWI) plays an important role in discriminating malignant from benign lesions in the prostate gland. The monoexponential model based on free water diffusion has been widely used in most of DWI studies in the prostate gland. However, this approach is insufficient to describe the diffusion process in heterogeneous biological tissue structure, such as cellular compartments and membranes. Recently, several approaches have been proposed to study the non-monoexponential diffusion behavior in the prostate gland. They include the biexponential model, intravoxel incoherent motion (IVIM) model and diffusion kurtosis imaging[1-4]. Aside from IVIM model, these models do not directly relate the parameters to a specific anatomical-physiological finding. Statistical model proposed by Yablonskiy et al. is an approach that presumes the distribution of diffusion coefficients in the imaging voxel and can provide more physiological information[5]. Thus, the purpose of this study was to investigate the shape of the distribution of diffusion coefficients in prostate cancer (PC) and healthy peripheral zone (PZ), and explore new parameters using the statistical model.

**Materials and Methods:**

Twenty-six patients (mean age, 71.9 ± 6.1 years) who were histologically proven to have PC by transrectal ultrasound (TRUS) - guided biopsy were included in this study. The mean preoperative prostate-specific antigen (PSA) level was 34.5 ± 112.4 ng/ml. Imaging was performed on a 3T or 1.5T MRI scanner (Achieva 3T and Ingenia 1.5T, Philips Healthcare, Eindhoven, the Netherlands) using a 16-channel (3T) or 32-channel (1.5T) phased-array coil. DWI was performed using 5 b-values (0, 500, 1000, 1500 and 2000 s/mm$^2$). Other parameters were as follows: TR/TE = 5000/49; 3.5 mm slice thickness with 0.1 mm gap; FOV = 240 × 240 mm; and matrix size = 256 × 256. Regions of interests (ROIs) were placed in cancerous tissue and in contralateral healthy PZ on DWI by the consensus of two experienced radiologists. We used a gamma distribution function instead of a Gaussian-type distribution function for the statistical model because the distribution of diffusion coefficients in PC were expected to have a low mean and a high standard deviation as reported in the previous study[1]. The gamma distribution function is given by the following equation: $\rho(D) = AD^{\alpha-1}\exp(-\beta D)$, where $A$ is a normalization constant, $\alpha$ and $\beta$ are shape and rate parameters, respectively. The parameters $\alpha$ and $\beta$ provide mean ($\alpha/\beta$) and variance ($\alpha/\beta^2$) of the gamma distribution. When the distribution of diffusion coefficients follows the gamma distribution function, the signal $S$ is obtained by the following expression: $S(b)/S_0 = \beta^\alpha/(\beta+b)^\alpha$. A statistical comparison of the curve fits between the biexponential and the statistical model was performed in each individual case on both PC and healthy PZ by $F$ tests using $x^2$ values of each fit. In addition, Welch $t$ tests were performed to assess statistical significance of the parameters of the statistical model [mean, standard deviation, ADC < 1.0 (%), ADC > 3.0 (%)] between PC and healthy PZ with $P$ values less than .05 considered significant.

**Results and Discussion:**

The statistical model based on gamma distribution functions provided statistically equal curve fits compared with biexponential functions in 92% (24/26) of PC and in 77% (20/26) of PZ, even though the biexponential functions were supposed to provide improved fits over the gamma functions due to their larger number of free parameters, suggesting the validity of the gamma distribution. Table 1 shows a summary of the statistical model parameters obtained from PC and PZ. Figure 1 and 2 show the probability density functions and cumulative distribution functions in all cases, respectively. The mean and the standard deviation were significantly lower in PC than in PZ. ADC < 1.0 (%) was significantly higher in PC than in PZ, and ADC > 3.0 (%) was significantly lower in PC than in PZ. We assume that ADC < 1.0 (%) and ADC > 3.0 (%) are linked to restricted diffusion and perfusion, respectively. These results are consistent with previous IVIM DWI studies[2, 3]. We also found that PC could be clearly distinguished from PZ by ADC < 1.0 (%).

Table 1: Results of statistical model parameters

| | Mean (mm$^2$/s) | Standard deviation (mm$^2$/s) | ADC < 1.0 (%) | ADC > 3.0 (%) |
|---|---|---|---|---|
| PC | 1.40 ± 0.33 | 1.44 ± 0.35 | 46.1 ± 8.5 | 17.5 ± 6.1 |
| PZ | 2.65 ± 0.13 | 1.93 ± 0.77 | 17.6 ± 6.0 | 33.4 ± 9.3 |
| *P*-value | < 0.001 | 0.005 | < 0.001 | < 0.001 |

Fig 1: Probability density function of PC and PZ with gamma distribution

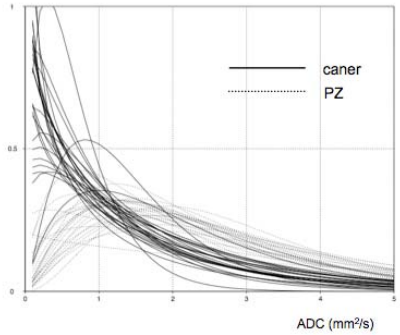
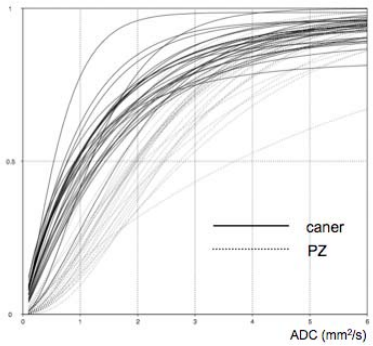



Fig 2: Cumulative distribution function of PC and PZ




**Conclusion:**

The statistical model based on a gamma distribution was suitable for describing the diffusion signal decay curves of PC and PZ. This approach provides additional insight for the physiological basis of DWI and allows us better correlation of diffusion signal decay and histologic findings.

**References:**

1) Shinmoto H, et al. Magn Reson Imaging. 2009;27:355-9. 2) Döpfert J, et al. Magn Reson Imaging. 2011;29:1053-8. 3) Shinmoto H, et al. AJR Am J Roentgenol. 2012;199:W496-500. 4) Rosenkrantz AB, et al. Radiology. 2012;264:126-35. 5) Yablonskiy DA, et al. Magn Reson Med. 2003;50:664-9.