Evaluation of intravoxel incoherent motion using the Fourier analysis for prostate cancer

Poster No.: C-0023
Congress: ECR 2015
Type: Scientific Exhibit
Authors: A. Ogura¹, K. Hayakawa², F. Maeda², N. Hayashi³; ¹Gunma/JP, ²Kyoto/JP, ³Maebashi/JP
Keywords: Pelvis, MR physics, MR, MR-Diffusion/Perfusion, Decision analysis, Physics, Tissue characterisation
DOI: 10.1594/ecr2015/C-0023

Any information contained in this pdf file is automatically generated from digital material submitted to EPOS by third parties in the form of scientific presentations. References to any names, marks, products, or services of third parties or hypertext links to third-party sites or information are provided solely as a convenience to you and do not in any way constitute or imply ECR's endorsement, sponsorship or recommendation of the third party, information, product or service. ECR is not responsible for the content of these pages and does not make any representations regarding the content or accuracy of material in this file.

As per copyright regulations, any unauthorised use of the material or parts thereof as well as commercial reproduction or multiple distribution by any traditional or electronically based reproduction/publication method is strictly prohibited.

You agree to defend, indemnify, and hold ECR harmless from and against any and all claims, damages, costs, and expenses, including attorneys' fees, arising from or related to your use of these pages.

Please note: Links to movies, ppt slideshows and any other multimedia files are not available in the pdf version of presentations.

www.myESR.org
Aims and objectives

Prostate cancer is the most commonly diagnosed cancer and the second leading cause of cancer deaths in American men (1-3). Commonly, prostate-specific antigen (PSA) testing is used for the screening of prostate cancer. Transrectal ultrasonography (TRUS)-guided prostate biopsy is accepted as the gold standard for diagnosis, while the most important determiners of prostate cancer prognosis are the Gleason score and tumor staging (4-6). Magnetic resonance imaging (MRI) of the prostate provides excellent anatomic information, and this technique is considered sufficiently sensitive for prostate cancer detection. Diffusion-weighted magnetic resonance imaging (DW-MRI) has been proven to improve prostate cancer detection.

Apparent diffusion coefficient (ADC) values are also important as regards prostate cancer detection. The ADC values of cancerous prostate tissue are generally lower than those of normal prostate tissues, particularly in the peripheral zone (PZ). Normally, the ADC of water molecules within living tissues is derived analytically from diffusion images, with an assumption that the water molecular diffusion is a random process (7-10).

Dynamic contrast-enhancement MR imaging (DCE-MRI) can evaluate vascular characteristics. Increased microvessel density will lead to an increase in blood flow, blood volume, and the surface area of vessel walls. An upturn in vascular endothelial growth factor production is likely to increase the permeability of these vessel walls. Blood flow, blood volume, and micro-vascular permeability-surface area product are all, in principle, quantifiable through analysis of contrast-enhanced MR imaging data by using distributed-parameter tracer kinetics models.

There are reports that intravoxel incoherent motion (IVIM) DWI may offer additional information regarding prostate cancer (11-14). The IVIM model predicts a much faster diffusing exponential component in the signal equation due to perfusion effects, which affects the overall signal, predominantly at low b-values (15). According to the IVIM DWI model, both pure extravascular molecular diffusion and microcirculation of blood within the capillaries (perfusion) can be separated using a bi-exponential decay function, providing additional parameters for tissue characterization.

The purpose of this study is to evaluate a novel method of data acquisition and an IVIM method for detection of prostate cancer. First, the theory behind the method is explained, then this technique is applied and evaluated, through comparison with the DCE-MRI approach.
Methods and materials

1. IVIM equation

\[ \frac{S}{S_0} = f \exp(-b(D^*+D)) + (1-f) \exp(-bD), \]  \hspace{1cm} (1)

Here, \( S \) is the measured signal intensity, \( S_0 \) is the signal intensity without the influence of diffusion, \( D \) is the diffusion coefficient of water, and the sequence-dependent b-value characterizes the diffusion weighting. In addition, \( f \) is the perfusion fraction, \( D \) is the (molecular) diffusion coefficient, and \( D^* \) is the pseudodiffusion coefficient, which depends on the mean blood velocity and the mean capillary segment length. Since the mean blood velocity is considerably faster than the mean molecular diffusion velocity of water, the flow-related pseudodiffusion coefficient, \( D^* \), is expected to be orders of magnitude greater than the tissue diffusion coefficient, \( D \). As a consequence, the first term (the perfusion-related component) in Eq. (1) becomes very small for high b-values and, hence, perfusion effects are detectable at low b-values. The signal decay as a function of the diffusion b-value is thought to consist of three parts. The signal decay related b-values and \( f, D^*, \) and ADC are shown in Figure 1.

2. The novel IVIM index

At first, the small b-value data (0 - 50 s/mm\(^2\)) were acquired in detail and used for IVIM analysis (Figure 2). Then, curve fitting was applied to the diffusion signals in the form of an exponential curve using the least squares method. Next, this fitting curve was transformed using Fourier analysis. Finally, the intercept value at 0.05 of the vertical axis was taken as the new IVIM index, in the form of the vascularity-value (V-value) (Figure 3).

3. Patients

In this study, the clinical and imaging data of 34 patients (age: 44-84 years; mean age: 67 years) with biopsy-proven prostate cancer were retrospectively evaluated. Ethical review board approval was obtained for this analysis, and informed consent was obtained from all patients. All of the 34 patients underwent a prostatectomy (after MR examination) and had biopsy-proved prostate cancer, with no relevant treatment history at the time of
imaging (such as radiotherapy or chemotherapy). In addition, dynamic contrast material-enhanced (DCE) MR images were available for 24 patients.

4. MR images data acquisition

Diffusion weighting was accomplished using a Stejskal-Tanner spin echo diffusion preparation with two mono-polar diffusion gradient pulses, followed by a single-shot echo-planar imaging readout at b-values of 0, 5, 10, 15, 20, 25, 30, 35, 40, 50, 80, 100, 200, 400, and 800 s/mm$^2$. For each b-value, diffusion weighted images were acquired with three orthogonal gradient directions, resulting in rotationally invariant trace images. A parallel imaging technique, sensitivity encoding, was used to reduce the gradient-echo train lengths by a factor of 2. The acquisition time of the IVIM DWI was 12 min 43 s.

5. Image analysis

For each patient, the largest diameter region of interest (ROI) was placed in the tumors found and referenced as T2-weighted images and ADC maps, while another ROI was placed in contralateral healthy tissue on images with b-values of 15.

The mean signal intensities over the ROIs were calculated for each b-value. According to the IVIM theory, the relative signal is given by Eq. (1) by means of a nonlinear least squares fit for solution of the D$^*$ and f indices. The ADCs were calculated using the signals of the DW images with b = 0 and 1,500 s/mm$^2$. In addition, a mono-exponential fit curve using the images of b = 0, 5, 10, 15, 20, 25, 30, 35, 40, 50 s/mm$^2$ was processed with the Fourier transform, and the intercept value at 0.05 of the Fourier transform curve was defined as the V-value.

6#Evaluation of dynamic contrast enhanced MRI

The signal intensity-time curves were interpreted independently by three radiologists, who were blind to all patient information. The curves were evaluated to general perfusion parameters, including peak signal intensities, initial slope, maximum slope for the initial 50 s after the contrast injection, wash-in rate, washout rate, and time-to-peak. The likelihood of the presence of cancer for the DCE-MRI images was indicated by a separately assigned score, using a five-point rating scale: 1 - not present; 2 - probably not present; 3 - possibly present; 4 - probably present; and 5 - definitely present. The averaged scores of the three radiologists were set as the DCE-MRI scores.
Evaluation of each index for IVIM

The index ratio is defined as the difference of each normal tissue and tumor index value divided by the mean, i.e.

\[ \text{Index ratio} = \frac{\text{Index value of normal} - \text{Index value of tumor}}{\text{Index value of normal} + \text{Index value of tumor}}. \]  (2)

The error of measurement range was defined as +-1%, and any data not satisfying this requirement were excluded.

For the 34 patients with prostate cancer, the prostate cancer detection rates of each index score (D*, f, ADC, and V-value) against the biopsy results were compared.

In addition, the agreement ratios of the 5 ranking evaluations of the DCE-MRI and each IVIM index were evaluated.
**Fig. 1:** Decomposition of the tri-exponential relative signal decay as a function of the diffusion b-values. The dashed line indicates three-part decay: IVIM, fast component, and slow component.

© School of Radiological Technology, Gunma Prefectural College of Health Sciences - Gunma/JP
Fig. 2: Detailed small b-value data (0 -50 s/mm²) were acquired and used for IVIM analysis.

© School of Radiological Technology, Gunma Prefectural College of Health Sciences - Gunma/JP
Fig. 3: Curve fitting was applied to the diffusion signals to generate an exponential curve using the least squares method. This curve was then translated by Fourier analysis. The intercept value at 0.05 of the vertical axis is the new IVIM index, as the vascularity-value (V-value).

© School of Radiological Technology, Gunma Prefectural College of Health Sciences - Gunma/JP
Results

1. Differentiation between tumor and normal tissue using each index

For evaluation of the measurement errors, the standard deviation of each index level of the normal tissue was calculated. This standard deviation defined an error of measurement range and appropriate data was excluded. The ratio of each index of prostate cancer against the biopsy results were ADC = 77%, D* = 53%, f = 56%, and V-value = 74% (Figure 4).

2. Agreement with dynamic contrast enhancement (DCE) evaluation and comparison of two complex indices

The agreement ratios of the evaluations of the DCE-MRI and each IVIM index were D* = 42%, f = 53%, and V-value = 81% (Figure 5). The tumor detection rate obtained for the ADC and V-value indices was 85%, while the corresponding value for ADC and DCE-MRI was 93%. The tumor detection rate of the ADC and V-value indices was 91% of the detection rate of the ADC and DCE-MRI indices together.
**Fig. 4:** Ratio of each prostate cancer index (ADC, D*, f, and V-value) for comparison with biopsy.

© School of Radiological Technology, Gunma Prefectural College of Health Sciences - Gunma/JP
Fig. 5: Agreement ratios of the 5 ranking evaluations of dynamic contrast enhancement-MRI and each IVIM index.

© School of Radiological Technology, Gunma Prefectural College of Health Sciences - Gunma/JP
Conclusion

More detailed data acquisition for low b-values was developed for IVIM, and these data were inserted into the IVIM equation using a non-linear least squares fit. The fitting curve was processed with the Fourier transform for evaluation of the IVIM curve shape. An intercept value at 0.05 of the Fourier-transform curve was defined as the V-value. The V-values of the novel index were compared with $D^*$ and f, as the conventional IVIM index, and with the diagnostic information of DCE-MRI regarding tumor vascularity, and it was found that detection based on the V-value was more accurate than the f and $D^*$ results. Therefore, it can be concluded that the V-value is effective as an IVIM index. Tumor detection using both the ADC and the V-value had 91% accuracy, in comparison with both the ADC and DCE-MRI. However, the V-value cannot be used to evaluate the washout, in contrast to the DCE-MRI, but it can be used to evaluate tumor vascularity. Therefore, the V-value approach can be used for patients for whom use of contrast media is not possible.
Personal information

Akio Ogura, PhD
Graduate School, Gunma Prefectural College of Health Sciences

Fumie Maeda, RT
Department of Radiology, Kyoto City Hospital

Katsumi Hayakawa, MD
Department of Radiology, Iwate Prefectural Kamaishi Hospital

Norio Hayashi, PhD
Graduate School, Gunma Prefectural College of Health Sciences
References
