

Measurement of Hydrogen Diffusion through PVA Hydrogel using Magnetic Resonance Imaging Method in Comparison with Consistency Assessment using Digital Penetrometer

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Abstract

A study of hydrogen diffusion behavior in the PVA (polyvinyl-alcohol) hydrogel had been done to measure diffusion coefficient (*Apparent Diffusion Coefficient/ ADC*) used as parameter of brain tumor grading. For our study, PVA hydrogel samples were prepared using freezing-thawing method with various concentration and number of freezing-thawing cycles. The ambiguity of brain tumor grading using ADC value, which is formed from Diffusion Weighted-Imaging 1,5 T, could be reduced enough with observing the result of correlation the ADC at b-value 1000 s/mm² and 3000 s/mm² with assessment of consistency measured using digital penetrometer based on microcontroller.

KEYWORDS: apparent diffusion coefficient, polyvinyl-alcohol, diffusion weighted imaging, digital penetrometer

I. INTRODUCTION

The fact that about two-thirds of the human body is made up of water, where each its molecule consists of two hydrogen atoms (¹H), of which makes MRI (Magnetic Resonance Imaging) possible. Diffusion-weighted magnetic resonance imaging (DW-MRI) is a highly sensitive tool for the detection of "Brownian motions", energized water molecules diffusing caused by heat associated with our body temperature, that characterize many brain pathologies including Brain Tumor. They are expressed, in diffusion weighted images, as changes in MRI signal intensity or as variations in the *Apparent Diffusion Coefficient* (ADC) of water [1, 2]. Brain infraction leading to high mortality and disability, in recent years, has been emerged to be applicable in early diagnosis by DW-MRI based on echo planar imaging (EPI) [3]. The measured signal intensity in the image with diffusion weighting is expressed by [4].

$$\begin{aligned} S(b) &= S_0 \exp^{-b(ADC)} \\ &= S_0 \exp^{-\gamma^2 G^2 \delta^2 (\Delta - \delta/3)(ADC)} \end{aligned} \quad (1)$$

with S(b) is the measured signal intensity in function of b-value, the parameter γ is a nuclear constant called gyromagnetic ratio, the parameter G is gradient pulses, the parameter δ is signal loss, the parameter Δ is time between the two pulses, and the ADC is the diffusion constant of water molecules.

DWI (*Diffusion Weighted Imaging*) and ADC value have

been studied in other clinical situations, including the differential diagnosis and grading of brain tumors. It is known that the higher cellularity in high-grade glioma, the lower ADC values. But in some cases DWI at a standard b-value ($b = 1000 \text{ s/mm}^2$) at 1.5 T hardly differentiates high-grade and low-grade because of overlapping signal intensities [S(b)] on DWI and ADC maps. Stronger gradients, recently, have permitted high b-value DWI particularly in 3T units which have higher SNRs compensating for it without increasing data acquisition time [5]. In this research, we prepared a sample to mimic the human tissue that would be scanned by DW-MRI 1.5 T at b-value 1000 s/mm² and 3000 s/mm².

There is a developing interest in the use of PVA cryogels to mimica range of tissue properties for MRI application, where the properties of the eminently resulting material can be exploited by the large effects of varying the concentration of PVA or the number of freezing-thawing cycle used in its preparation [6]. The suitable properties are including biocompatible, lack of toxicity due to chemical reaction, higher mechanical strength compared to the one formed by chemical method [7]. It has been described by the illustration in Figure 1 that the structure of PVA cryogels, which is a PVA hydrogels obtained by freezing-thawing (F-T) technique, consists in three phases; a water phase, amorphous phase and a crystalline phase [8]. According to recent experiment, increasing number of freezing-thawing cycles would increase the crystallite, the degree of physical crosslinking and rigidity of hydrogel, decrease water diffusion coefficient which is ADC in this research [9, 10].

On the other hand it has been assembled a digital microcontroller-based penetrometer by group of instrumentation physics department ITS [12]. The penetrometer provides kinetic energy which causes the penetrometer shaft to

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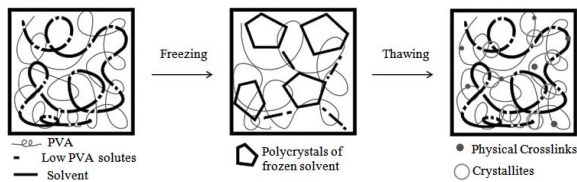
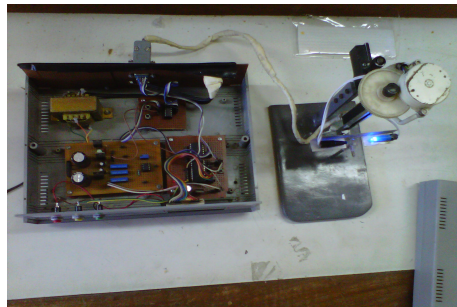


FIG. 1: From left to right; a low PVA concentration; the solvent crystals growth; the motion of amorphous PVA chains restricted by crystalline phase. It is a cryogelation process, gel formation via entanglement, hydrogen bonding and formation of crystallites. Reproduced from [11] adapted [8] for cryogelation.



(a)



(b)

FIG. 2: From left to right; digital penetrodrometer based on microcontroller with reset, up, and down button; electrical design of digital penetrodrometer [12].

penetrate through the sample by mechanical properties, motor stepper. The sample resistance relating to the sample consistency will be restraining the tip of the digital penetrodrometer causing LED light is restricted by the needle, photodiode sensor will send a pulse to microcontroller ATMEGA16 causing the controlled motor stepper stops. In our experiment, we prepared PVA hydrogels with different concentration and number of freezing-thawing cycle. We measured the consistency of PVA sample using digital penetrodrometer and ADC value from DW-MRI 1.5 T at b-value 1000 s/mm² and 3000 s/mm². We would also observe the correlation between these two data, by using Pearson Correlation, in order to increase the assessment of brain tumor grading.

II. MATERIAL AND METHOD

Hydrogel PVA Preparation

In our experiment, PVA (Mw = 60,000, degree of hydrolysis 98%, Merck Schuchardt, Germany) were used for PVA solution. According to a recent experiment result [13], PVA hydrogel samples were prepared by dissolving fully hydrolyzed PVA of 7,5, 10, 12,5, 15 wt% with deionized water (temperature 28,4°C, salt 0 ppt, pH 7, conductivity 0,01μS), heating up 100°C, in steady mixing which used hotplate stirrer Cimarec Digital-Thermolyne with magnetic stirring bars PTFE BRAND 137135 during an hour. The solutions were loaded into cylindrical plastic containers (φ55 mm × 95 mm) before cooling at room temperature for 3 h. Cryogelation process were stimulated by doing two to five freezing-thawing cycles at -20°C for 12 h and 25°C for 12 h.

ADC Measurement using DW-MRI

We used 1,5 T scanner (Signa Horizon; GE Medical System, Milwaukee, WI, USA) - standar head coil 8HBRAIN for Diffusion Weighted-MRI study. ADC value were gained from MRI with Diffusion-Weighted Imaging (DWI) method following Stejskal-Tanner sequence [13] and performed by using echo-planar imaging (EPI), FOV 24 × 24 cm, matrix size 512 × 512, section thickness 5 mm, frequency 256, scan time 1:25, TR = 5000, TE = 92,4 for b-value 1000 s/mm²; dan TR = 5000, TE = 116 for b = 3000 s/mm².

ADC value was calculated by Functool software (GE Medical Systems) and obtained by calculating Signal Intensity (SI) on DWI after placing seven uniform region of interest (ROIs) in each sample. According to a recent experiment result [10], ADC value were calculated by averaging ADC values from several ROIs for each sample.

Consistency Measurement using Digital Penetrodrometer

We used in this experiment the digital penetrodrometer designed by Group of Instrumentation-Departement of Physics Institut Teknologi Sepuluh Nopember [14].

The samples were placing under digital penetrodrometer needle, which was a stainless steel blunt end cylinder φ3 mm × 50 mm. The zero point of penetrodrometer was set to the samples, and then the data taken were seven rapidly different points for each sample. The depth of penetration was indicated the sample's consistency and would be correlated with the diffusion coefficient measured by DW-MRI.

III. RESULT AND DISCUSSION

The result from ADC measurement using different b-value in DW-MRI for PVA hydrogel samples with different concentration and number of freezing-thawing cycle are described in Figure 3 and Figure 4. The result is analog

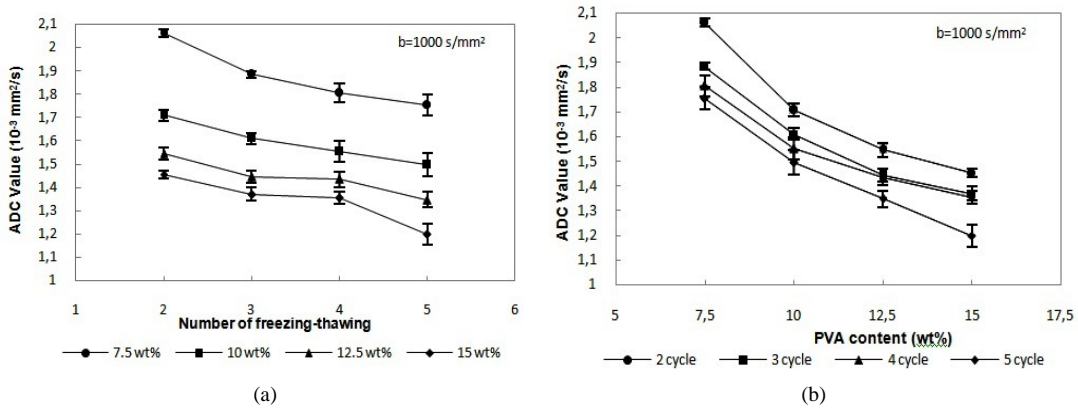


FIG. 3: From left to right; ADC values from PVA hydrogel at DW-MRI $b = 1000 \text{ s/mm}^2$ as function of freezing-thawing cycle at different PVA concentration; ADC values from PVA hydrogel at DW-MRI $b=3000 \text{ s/mm}^2$ as a function of PVA concentration at different number of freezing-thawing.

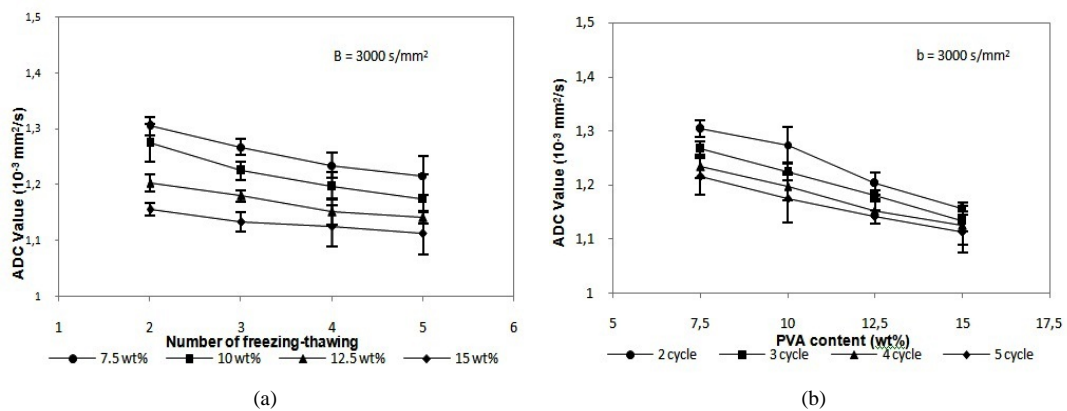


FIG. 4: From left to right; ADC values from PVA hydrogel at DW-MRI $b = 3000 \text{ s/mm}^2$ as function of freezing-thawing cycle at different PVA concentration; ADC values from PVA hydrogel at DW-MRI $b = 3000 \text{ s/mm}^2$ as a function of PVA concentration at different number of freezing-thawing.

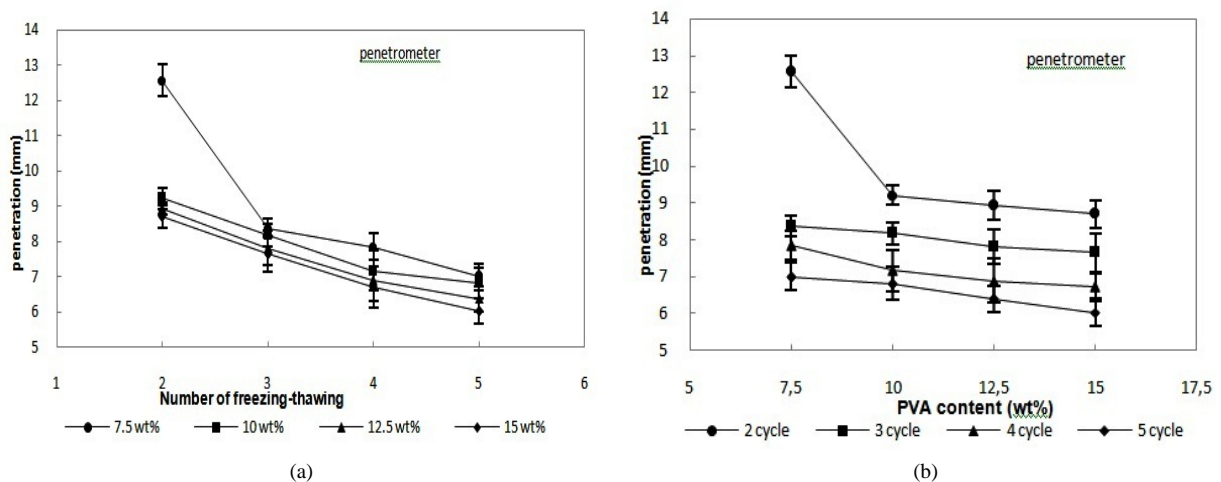


FIG. 5: From left to right; Consistency from digital penetrometer measurement as a function of number of freezing-thawing cycle at different PVA concentration; Consistency from digital penetrometer measurement as a function of PVA concentration at different number of freezing-thawing cycle.

TABLE I: Pearson Correlation of two data.

Data	2 cycles	3 cycles	4 cycles	5 cycles	7.5 wt%	10 wt%	12.5 wt%	15 wt%
b = 1000	0.96	0.96	0.99	0.96	0.98	0.99	0.94	0.92
b = 3000	0.77	0.99	0.96	0.97	0.93	0.99	0.99	0.98

with our hypothesis of higher diffusion coefficient with lower concentration and lower number of freezing and thawing [10, 15]. In Figure 4, it is showed that the linearity of the ADC value graph at b-value 3000 s/mm² is better than ADC graph at b-value 1000 s/mm² which is in line with the sample parameter that we used.

The consistency values from digital penetrometer measurement are showed by Figure 5. In the Table I, it is showed that both data at b-value 1000 s/mm² and b-value 3000 s/mm² have good correlation with physical measurement of consistency assessment using digital penetrometer.

IV. CONCLUSION

A study of hydrogen diffusion behavior in the PVA hydrogel to measure diffusion coefficient (Apparent Diffusion Coefficient) used as parameter of brain tumor grading had been done. A bare differentiating of brain tumor grading, by applying conventional DW-MRI 1.5 T b value 1000 s/mm², can be reduced by adding other parameter which is b-value 3000 s/mm². However higher b-value at conventional DW-MRI 1.5 T are not usually used in clinical practice because of poor image quality, so both of b-value 1000 s/mm² and higher are recommended for brain tumor grading.

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