SNR<sub>o</sub>, T1 and T2 characteristics of poly(vinyl) alcohol (PVA) MRI slime phantom with different PVA/borax ratio

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Abstract. Eleven PVA slime phantoms with different PVA/borax ratios were prepared using PVA and borax solution. The phantoms were scanned using Siemens 3-T Magnetom Verio MRI system using spin echo (SE) and turbo spin echo (TSE) sequences to obtain axial T1 and T2 weighted images respectively. The signal-to-noise ratio (SNR) of all samples was calculated implementing the region of interest (ROI) analysis. The T1 and T2 relaxation equations were then fitted to the experimental SNR vs. TR and SNR vs. TE curves for saturation (SNR<sub>o</sub>), T1 and T2 determination. Despite different PVA/borax ratios, SNR<sub>o</sub> was found to be constant while T1 and T2 increased slightly for higher borax concentration. The slime phantoms fabricated in this study has the potential as an alternative to agarose gel phantom.

1. Introduction

An MRI phantom is important for evaluating image quality, determining limitation of the application range and establishing standardization [1]. MR phantom is also helpful to train new MRI operators, development of new systems, pulse sequences, adjusting and fine-tuning the imaging parameters [2].

An MRI phantom must have the following characteristics; relaxation times equivalent to human tissues, dielectric properties equivalent to human tissues, homogenous relaxation times and dielectric properties throughout the phantom, the ease of handling and chemical and physical stability over an extended time [3]. For testing imaging systems and algorithms in the laboratory, fluid-based phantoms such as agarose are often the most appropriate [4]. A major disadvantage of fluid phantoms is that they are often unstable over a prolonged period and they are difficult to be transported [5]. The aim of this study was to explore the potential of other materials such as slime as MRI phantom.

Poly (vinyl) alcohol (PVA) slimes are biodegradable, toxic-free, inexpensive, biocompatible and non-carcinogenic. Slime has a physically and chemically cross-linked structure in a 3-D network of hydrophilic polymer and able to retain a large quantity of water and/or biological solution while keeping their structural integrity during deformation [6]. Using an appropriate ratio of PVA and water, a formation that possesses tissue-mimicking properties can be formed [7]. Borax ion serves as a cross-linked agent. It is tetra functional during the reaction with the –OH group. Therefore, it is effective for...
creating the 3D gel networks from PVA where almost all the spaces within the gel are filled-up by water molecules in the solvent [8]. However, if borax is used in excess, no gel-like mixture is developed [9].

The objectives of this study were to determine the T1 and T2 characteristics of PVA slime phantom with different PVA/borax ratios by measuring the SNR of the phantoms using T1 and T2 clinical MRI protocols.

2. Materials and Methods

2.1. Materials and apparatus

The materials used for the slime phantom are as follows: i) Borax (sodium tetraborate, [Na₂B₄O₇·10H₂O]) as gelling agent; ii) PVA powder, (C₄H₆O₂)ₙ, as the main ingredient for slime phantom; iii) distilled water and iv) 70-ml transparent sterile plastic container. Both sodium tetraborate and PVA powders were supplied by Chemiz (M) Pte. Ltd. The 70-ml transparent sterilized plastic containers were used to contain the phantoms. The apparatus used were digital weighing scale, 800 ml beaker and hotplate with magnetic stirrer.

2.2. Preparation of slime phantom

11 sets of PVA slime phantom with different borax content were prepared by mixing PVA and borax solutions proportionately. PVA solution was prepared by mixing 20.0 g of PVA and 500 ml of distilled water in a flask equipped with magnetic stirrer. The mixture was heated and stirred at temperature slightly below 100°C to avoid boiling of the solution. The heating continued until a complete dissolution of the polymer has been achieved. The change of the solution’s color from murky to crystal-clear indicated that a uniform distribution state has been achieved. Borax solution with 4% concentration was separately prepared in a similar manner.

Both solutions were mixed in a 70-ml transparent sterilized plastic container in specific proportions as shown in Table 1. Each phantom was labelled accordingly. The container’s lid was air-tight closed. All the prepared phantoms were stored at room temperature in a desiccator for two days.

| Phantom | V_{borax}/ml | V_{PVA}/ml | Borax:PVA |
|---------|--------------|------------|-----------|
| 1       | 0            | 70         | 0:10      |
| 2       | 7            | 63         | 1:9       |
| 3       | 14           | 56         | 2:8       |
| 4       | 21           | 49         | 3:7       |
| 5       | 28           | 42         | 4:6       |
| 6       | 35           | 35         | 5:5       |
| 7       | 42           | 28         | 6:4       |
| 8       | 49           | 21         | 7:3       |
| 9       | 56           | 14         | 8:2       |
| 10      | 63           | 7          | 9:1       |
| 11      | 70           | 0          | 10:0      |

Table 1. Quantity of borate, PVA and distilled water for slime phantom preparation

2.3. Image acquisition

The MRI data were acquired using Siemens Magnetom Verio 3-Tesla MRI system at the Department of Radiology, Hospital Canselor Tuanku Muhriz. The plastic container containing PVA slime phantoms and distilled water were inspected for leakage and any presence of air bubbles and foreign particles before being scanned. They were then positioned horizontally in the 32-channel head coil by using a home-made sample holder at the iso-centre of the magnet bore. All the six phantoms were
scanned simultaneously. The spin echo (SE) and turbo spin echo (TSE) sequences were applied to obtain the axial T1 and T2 weighted images respectively. T1 weighted images were obtained using a constant TE = 15 ms and TR = 100, 150, 200, 300, 600, 800, 1000, 1200, 1800, 2400, 3600, 4800, 5600, 6400 and 8000 ms. The T2 weighted images were obtained using a constant TR = 4970 ms and TE = 69, 82, 96, 110, 123, 137, 151, 165, 178, 192, 206, 220, 233, 247 and 261 ms. Other imaging parameters include slice thickness = 3.0 mm, matrix size = 64 × 64, field of view (FOV) = 230 × 230 mm and voxel size = 0.6 × 0.4 × 3.0 mm. All the images acquired were stored in a CD-ROM in DICOM format.

2.4. SNR determination

Image-J software (The National Institutes of Health, NIH) was used to measure the signal-to-noise ratio (SNR) for all phantoms. The middle slice from each volume measurement of the phantoms was chosen for SNR evaluation. The image selected was visually ensured to have a spatially homogenous distribution of signal intensity [10]. From the acquired images, the mean signal intensity of the phantom (I_p), signal intensity of the background noise (I_b) and standard deviation of the background noise (σ_b) were computed. Three circular ROIs with the size of 5 mm² were specified on the phantom images and I_p were obtained and averaged. Another circular ROI with the size of 40 cm² was drawn at the background, outside the phantom images in order to obtain I_b and σ_b. The SNR value for each phantom across all TEs and TRs were then calculated using the formula SNR = (I_p - I_b)/σ_b.

2.5. T1, T2 and SNR, determination

The T1 and T2 values of the phantoms were determined based on the SNR vs TR plot (T1 curve) with the equation of SNR ∝ 1 – e^(TR/T1) and SNR vs TE plot (T2 curve) with the equation of SNR ∝ e^(TE/T2) respectively [11]. The experimental data were fitted to both the equations using MATLAB® R2018b (The Math Works, Inc., Natick) curve fitting toolbox. The T1 and T2 values were obtained upon achieving the minimum sum of squared difference between the observed and fitted data. Likewise, by referring to the fitted T1 curve, the saturation value (SNR_s) was also determined. The 95% confidence interval (CI), standard sum of errors (SSE) and the R² of fit were also computed. The R-square of fit is the correlation coefficient between the observed and fitted data and the ideal value of R-square is 1. The T1 and T2 curves in this study were fitted in such way that the R² of fit is maximised and the SSE is minimised.

3. Results and Discussion

3.1. The effects of different borax/PVA on SNR_s, T1 and T2

Figure 1 (left) shows the saturation (SNR_s) values for the phantoms with different borax proportion. The SNR_s was found to be constant for all PVA/borax ratios. The average SNR_s value was calculated to be 579. SNR_s is largely influenced by the density of water in the PVA slime phantom. It seems that even though the ratio PVA/borax is changed, the total water content in the phantoms was not significantly changed. This is due to the same quantity of water that was used in preparing both the PVA and borax solutions. The fluctuation of SNR_s value between 540 and 616 with a standard deviation of 22 could be due to experimental error during the preparation of the solutions as well as due to evaporation of water molecules that cannot be avoided. Future research should take water molecules loss during preparation into a serious consideration due to its strong influence on SNR_s.

Figure 1(b) shows the change in T1 and T2 as borax proportion is increased. T1 is always longer than T2 irrespective of borax proportion. The average T1 value (3423 ms) is about 3.4 times the average of T2 value (276 ms). The phantoms have T1 and T2 that is equivalent to synovial fluid and blood respectively at 3.0T MRI [12]. The T1 and T2 values of PVA slime phantoms are similar with human tissues. Both the T1 and T2 values increase slightly after borax proportion is increased beyond 3. An increase in T1 or T2 values mean that the T1 and T2 curves relaxed slower and the curve are shifted to the right. A longer T1 relaxation time means that the oscillation frequency of the spins in the
surrounding molecules is much slower or faster than the Larmor frequency of the spins [14-15]. More time is needed for the spins to transfer their energy to the surrounding [14-15]. A longer T2 relaxation means that the spins stay in precession state (minimal relaxation) longer. A comprehensive discussion on T1 and T2 relaxations of the PVA slime phantom based on dipole-dipole interaction can be found in our separate communication [14]. Recent findings on the use of T2 weighted images to assess inhomogeneity [16] indicate the importance of similar study to be conducted in the future.

4. Conclusions
The PVA slime phantom has the potential as an alternative to agarose gel phantom as this study demonstrates SNR, T1 and T2 values of PVA slime phantoms that are constant and similar with human tissues. However, further studies are necessary to investigate the chemical and physical stability of the PVA slime phantom over a long period of time.

5. References
[1] Mano I, Goshima H, Nambu M and Iio M 1986 Magn. Reson. Med. 3(6) 921-26
[2] Yoshimura K, Kato H, Kuroda M, Yoshida A, Hanamoto K, Tanaka A, Tsunoda M, Kanazawa S, Shibuya K, Kawasaki S and Hiraki Y 2003 Magn. Reson. Med. 50 1011-17
[3] Chen C C, Wan Y L, Wai Y Y and Liu H L 2004. J. Dig. Im. 17(4) 279-84
[4] Hellerbach A, Schuster V, Jansen A and Sommer J 2013 Plos One 8(8) e70343
[5] Hebben J C, Price B D, Gibson A P and Royle G 2006 Phys. Med. Biol. 51(21) 5581-90.
[6] Han J, Lei T and Wu Q 2014 Carbohydrate Polymers 102 306-16
[7] Jiang S, Liu S and Feng W J. Mech. Behav. Biomed. Mat. 4(7) 1228-33
[8] Casassa E, Sarquis A and Van Dyke C 1986 J. Chem. Educ. 63(1) 57-60
[9] Ochiai H, Kurita Y and Murakami I 1984 Macromol. Chem. Phys. 185(1) 167-72
[10] Dietrich O, Raya J G, Reeder S, Reiser M F and Schoenberg S O 2007 J. Magn. Reson. Im. 26(2) 375-385
[11] Yusoff A N, Abdul Rashid N S and Usman Ali S 2018 J. Phys. Conf. Series 1083 012017
[12] Hatori K, Ikemoto Y, Takao W, Ohno S, Harimoto T, Kanazawa S, Oita M, Shibuya K, Masahiro K and Hirokazu K 2013 Med. Phys. 40(3) 032303
[13] Ying Yih Y, Hui Sin T, Azhar N A A, Abdul Manan H, Awang M N A and Yusoff A N 2019 Solid State Sci. Technol. 27(1&2) 105-21
[14] Yusoff A N, Ding A Z, Azman N, Awang M N A, Abdul Manan H 2019 Solid State Sci. Technol. 27(1&2) 51-67
[15] Dwihapsari Y, Asdiantoro E and Maulidiyah N 2020 Appl. Magn. Reson. 51(1) 59-69

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