

HOMOGENEITY AND STABILITY OF POLY (VINYL ALCOHOL) SLIME PHANTOM WITH DIFFERENT BORAX CONCENTRATION

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ABSTRACT

Many works have been carried out by researchers to produce phantoms that can replace agar as potential MRI phantom but can be fabricated from cheap and available materials. One potential material is the slime. The possibility to use this material as MRI phantom lies on the following characteristics; soft, viscoelastic, cross-linked physically and chemically able to retain a large quantity of water and possess structural integrity during deformation. However, the information on the homogeneity and stability of the slime under MRI environment is still lacking. This study investigated the homogeneity and stability of poly(vinyl alcohol) (PVA) slime phantom and determine its suitability and potential for MRI phantom. Four sets of slime phantoms with different borax concentration, $\rho = 0.0075$ g/ml, 0.0125 g/ml, 0.0175 g/ml and 0.0225 g/ml were prepared by mixing borax solution (borax powder mixed with distilled water) with PVA glue. The T1 and T2 weighted images of the phantoms were acquired using a 3-T MRI system via a turbo spin echo pulse (TSE) sequence for homogeneity investigation. The scans were carried out at four time points (TP) to investigate the stability of the phantoms. The T1 curves showed that SNR increased exponentially as TR was increased (TE fixed) while the T2 curves demonstrated an exponential decrease of SNR as TE was increased (TR fixed). The SNR values measured from selected regions of interest (ROIs) within each phantom were homogeneous but decreased markedly over time. In contrast, the T1 and T2 values were found to be stable over time and in good agreement with the average values of human tissues. The results are promising at least in the context of phantom homogeneity and stability. Further studies are necessary in order to obtain suitable slime phantoms for MRI in actual scale which homogeneity and stability would withstand a longer period of time.

Keywords: Slime; MRI phantom; Relaxation; SNR; T1; T2

INTRODUCTION

As the development in magnetic resonance imaging (MRI) continues to propel into a greater height each year, it is important to maintain a good quality assurance (QA). QA is one of the important aspects in MRI as the scanner is prone to technical, image quality and instrumental problems. Therefore, the use of a standardized MRI phantom with consistent and uniform QA quality is needed to ensure that the images produced are of diagnostic quality and to avoid misinterpretation by the clinicians [1].

MRI phantom is an important apparatus in MRI as it serves in the testing the capability of an MRI scanner, verifying the image quality and contrast and detecting any safety defect on the scanner [2]. Furthermore, MRI phantom is very helpful in the training of new MRI operators and in developing new systems, pulse sequences and in adjusting and fine-tuning the imaging parameters [3]. In order to fulfil the criteria mentioned above, the materials used as MRI phantoms should i) have relaxation times that is identical to human tissue; ii) have constant relaxation times all over the phantom itself; iii) be able to be moulded with similar shape and size of human organs; iv) be easy to handle and v) should stay chemically and physically stable over a long period of time [3]. The materials used as MRI phantom should also remain toxic-free. Phantoms that contain toxic elements are difficult to handle especially during transportation and disposal. Broken MRI phantoms may contaminate the MRI scanner and endanger the life of patients and the MRI operators [4]. Therefore, this study is carried out to explore the potential of other materials such as slime to become MRI phantom.

In a previous study [9], it was found that PVA or poly(vinyl alcohol) is a synthetic polymer with the repeating $-\text{CH}_2-\text{CH}(\text{OH})-$ units. PVA is insoluble in organic solvents but soluble in aqueous solution. It is generally a safe chemical and has minimal effects on the environment as it can be biodegraded by several omnipresent microorganisms through the enzymatic processes [10]. PVA is widely used in many fields including household items as it acts as a thickening agent for common household white glue or other adhesive mixtures. PVA has a very low oral toxicity and cannot be absorbed by gastrointestinal tract even though administered orally [10]. It was also reported [10] that there was no evidence of carcinogenic effects from PVA after two years of study on mice. Therefore, PVA is generally safe for the formation of MRI phantom.

Borax is also known as sodium tetraborate with a chemical formula $[\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}]$. It is a highly alkaline salt that can be hydrolyzed in water solution to produce boric acid-borate buffer with a pH of around 9 [11]. Borax is selected in this study as it can form slime with PVA glue. Slime has the following characteristics; soft, viscoelastic and cross-linked physically and chemically in a 3-D network of hydrophilic polymer, able to retain a large quantity of water and/or biological solution while keeping their structural integrity during deformation [12]. Almost all PVA slimes are biodegradable, toxic-free, inexpensive, biocompatible and non-carcinogenic [12]. When borax powder dissolves in water, it will form a boric acid-borate buffer i.e. $\text{B}(\text{OH})_3 +$

$2\text{H}_2\text{O} \rightleftharpoons \text{B}(\text{OH})_4^- + \text{H}_3\text{O}^+$. Polyol gels cannot be produced with boric acid alone. It must be partially neutralized into borate ion form to act as a cross-linking agent to react with the -OH group of PVA [11]. Borate ion is tetra functional during the reaction with the -OH group and therefore it is effective for creating the 3D gel networks from poly(vinyl alcohol) where almost all the space within the gel is filled up by water molecules in the solvent [11]. When a diluted PVA solution and an excess borate is used, no gelation is developed [13]. Due to the high intensity of water inside the PVA-borax slime, it could be transformed into different shapes by hand. When two blocks of slime are knead together, they will fuse with one another [12].

When an external force is applied to the slime, such as stretching or compressing, the flexibility within the slime is produced by the reversible and exchangeable bonds dynamically formed between $\text{B}(\text{OH})_4^-$ and OH groups in the PVA. This enable the slime to withstand the intense force and dissipate the energy received without irreversible changes to the structure [12]. The slime also possesses non-Newtonian fluid behaviour; the ability to bounce back slightly when thrown to a hard surface and to stretch to form a thin film when low stress is applied [12].

The objective of this study was to determine the homogeneity and stability of slime phantom by measuring the signal to noise ratio (SNR) of the phantoms using T1 and T2 MRI protocols for different ρ and at different time points (TP) after preparation. The development of slime as MRI phantom can be considered as a novel approach in the fabrication of MRI phantom. To our knowledge, no study has been conducted before to test the potential of slime as MRI phantom. However, similar research with other gelling agent such as agarose, xanthan gum, carbomer-980 gel and carrageenan has been carried out in previous works [4, 6 and 8]. In this study, four sets of MRI slime phantoms with different borax concentration (ρ) were produced and tested. The slime phantoms were prepared in the laboratory by using the PVA glue as the main matrix and the borax powder as the relaxation modifier. All the samples were simultaneously scanned using a 3T-MRI system at four different time points.

EXPERIMENTAL

Preparation of Slime Phantom

Four PVA slimes with different ρ (0.0075 g/ml, 0.0125 g/ml, 0.0175 g/ml and 0.0225 g/ml) were prepared using a conventional mixing method. Different masses of borax powder (Chemiz, USA) ranged from M = 0.75 g, 1.25 g, 1.75 g and 2.50 g were weighed using electronic weighing scale (OHAUS[®] Pioneer PA 210C) and were separately added into four beakers containing 100 ml distilled water (V). The solutions (V_{Borax}) were stirred using magnetic stirrer on a hot plate at 80 °C for 5 minutes. The changes of solution appearance from murky to crystal clear indicate that the borax powder has completely dissolved and the solution is in a uniform distribution state. The borax solution was let to gradually cool down to room temperature.

100 ml of PVA glue (V_{PVA}) (Q-Stationers Sdn. Bhd., Malaysia) is then gradually added

to the borax solution using a 20-ml syringe while the solution is stirred manually using glass rod. The slime is formed when the borax solution has completely diffused with PVA glue. The slimes were filled into the transparent 60-ml sterile plastic container. The container lid was tightly closed and sealed with Parafilm® M All-Purpose Laboratory Film (Bemis Company, Inc). All the slimes were then stored and isolated in a polystyrene box to prevent extreme changes in temperature and humidity. The containers were positioned and maintained vertically as the solution hardened. The phantoms were continuously observed for any presence of foreign materials and growth of fungus for at least once a week and just before the scan is performed. Details about the quantity of borax, PVA and distilled water used are given in Table 1.

Table 1: Quantity of borax, PVA and distilled water for slime phantom preparation

Phantom	M/g	V/ml	ρ/gml^{-1}	V_{PVA}/ml	$V_{\text{Borax}}/\text{ml}$
1	0.75	100	0.0075	100	100
2	1.25	100	0.0125	100	100
3	1.75	100	0.0175	100	100
4	2.25	100	0.0225	100	100

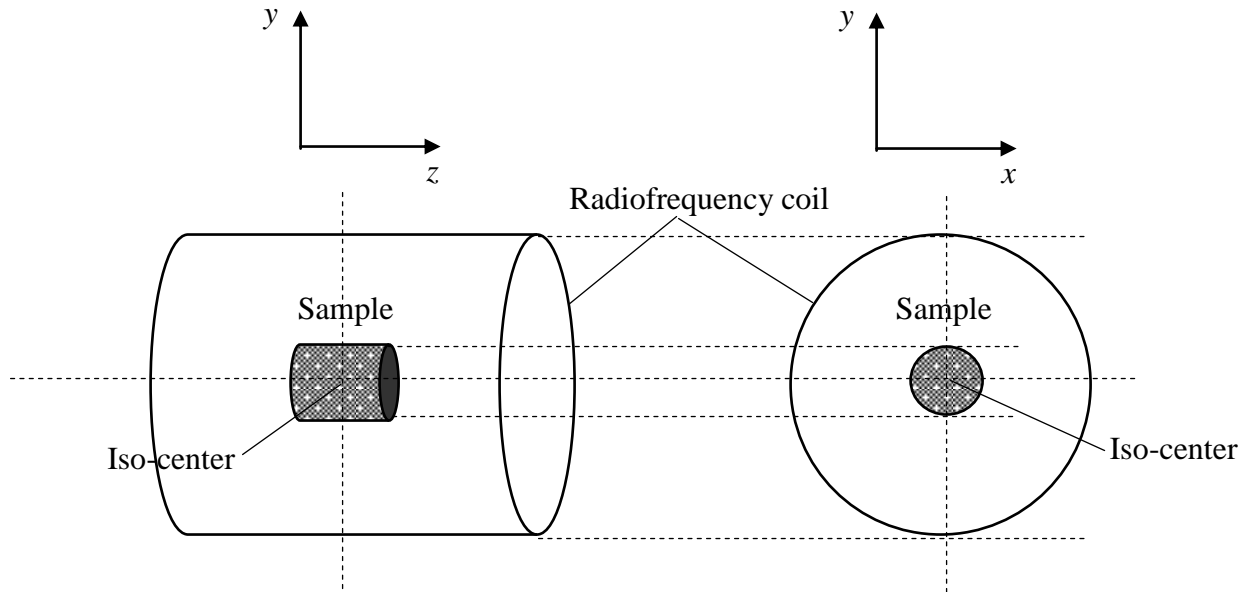


Figure 1: Position of the sample inside the coil; left: lateral view and right: axial view. The sample and the coil were positioned at the iso-center of the magnet

Data Acquisition and Analyses

The MRI data were acquired using a 3-T Siemens Magnetom Verio MRI system in the Department of Radiology, Hospital Canselor Tuanku Muhriz. The slime phantom was

positioned horizontally at the iso-centre of the magnet bore inside a head coil (See Figure 1). This will ensure that all samples will be subjected to the same magnitude of magnetic field at all time-points. For the MRI system used, the body coil located just beneath the inner wall of the scanner bore delivered the radiofrequency (RF) pulses. The reception of the RF signal was done by the head coil. The turbo spin echo (TSE) sequence was used to measure axial T1 and T2 relaxations. The acquisition parameters for T1 measurements were TE = 21 ms, TR = 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500 and 2000 ms. The acquisition parameters for T2 measurements were TR = 10000 ms, TE = 62, 77, 93, 108, 123, 139, 154, 170, 185, 200, 216, 231, 247, 262, 278 and 293 ms. Other imaging parameters were field of view (FOV) = 150 × 150 mm, slice thickness = 3.0 mm, matrix size = 64 × 64 and voxel size = 0.6 × 0.5 × 3.0 mm. For the standard MRI water phantom (Siemens Spherical Phantom D170 4762311 K2200, 56-cm circumference, 1.25 g NiSO₄/1000 g H₂O), slightly different imaging parameters were used which were TR = 100, 150, 200, 300, 600, 1200, 2400, 4800 and 8000 ms (TE = 10 ms); TE = 69, 82, 96, 123, 137, 151, 165, 178, 192, 206, 220 and 247 ms (TR = 4970 ms).

For signal-to-noise (SNR) determination, region of interest (ROI) based approach was used [14, 15]. SNR evaluation is conducted on the middle axial slice acquired from each phantom. The mean signal intensity of phantom (I_p), the mean signal intensity (I_b) and standard deviation (σ_b) of background noise were measured on acquired images. Three circularly-shaped ROIs with the size of 1.03 cm² were drawn at the centre of the image respectively to measure the signal intensity of slime phantom. Average signal intensity of each phantom is calculated based on the ROIs. The intensity of the background noise (I_b) and its standard deviation (σ_b) were obtained from three ROIs with the size of 5.93 cm² drawn on background outside the image of the phantom. The SNR were calculated using the formula $SNR = (I_p - I_b)/\sigma_b$ [15] in which the I_b and σ_b were the average values obtained across all TE and TR.

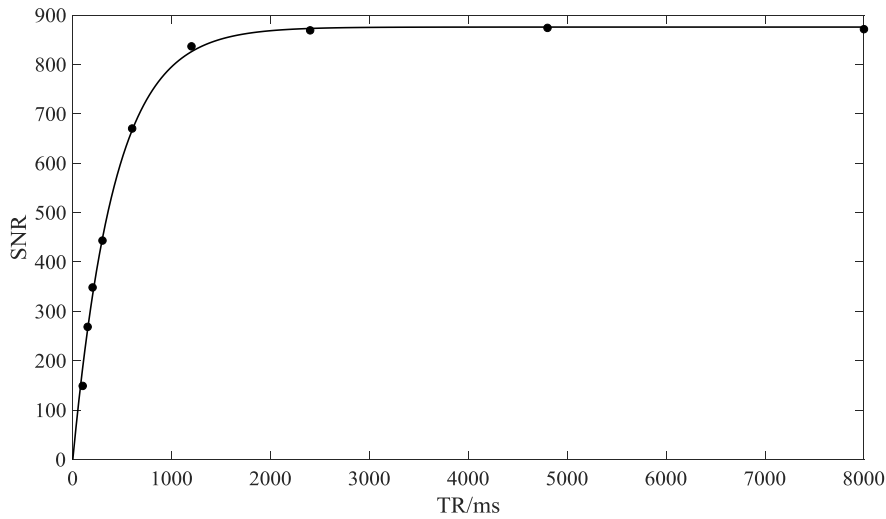
T1, T2, and SNR_o Determination

The T1 values for the standard MRI water phantom and the slime samples were determined from the SNR vs. TR plot (T1 curve) using the equation $SNR(TR) = SNR_o(1 - e^{-TR/T1})$ [4, 14]. The respective T2 values were determined from the SNR vs. TE plot (T2 curve) using the equation $SNR(TE) = SNR_{x-y}(e^{-TE/T2})$ [4, 14]. Both equations were fitted to the experimental data using Matlab R2018b Curve Fitting Toolbox (The Mathworks, Inc. USA). The most suitable T1 and T2 values were obtained upon achieving the minimum sum of squared difference between the observed and the fitted data. Similarly, using the curve fitting method, the saturation value (SNR_o) for each respective T1 curve and the starting value (SNR_{x-y}) for each T2 curve were also determined. The effects of ρ and time after preparation on T1, T2, SNR_o and SNR_{x-y} were evaluated and studied.

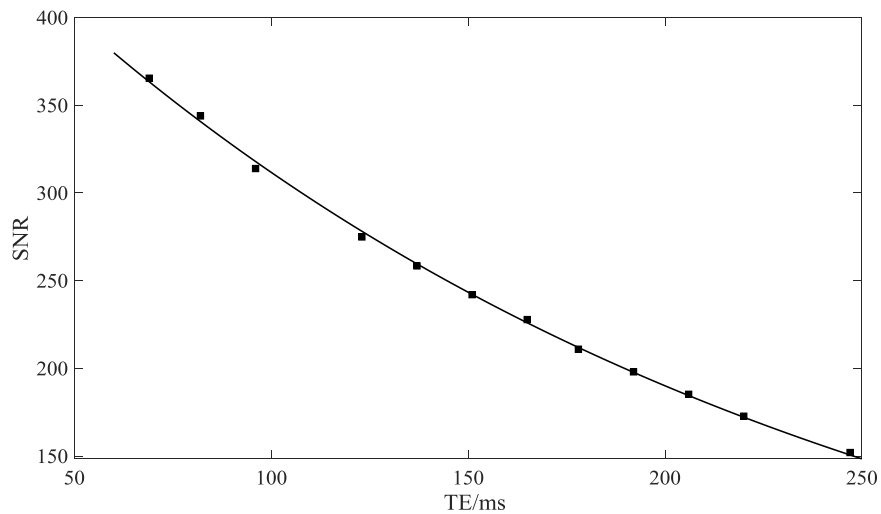
RESULTS

Standard MRI Water Phantom

Figure 2(a) shows the results obtained from the measurement of SNR as a function of TR for the standard water phantom. It can be clearly seen that the observed data (dark symbol) were well fitted and fulfil an exponential behaviour of the form $SNR \propto 1 - e^{-TR/T1}$. It was found that the minimum sum of squared difference between the observed and fitted data is achieved when $T1 = 419$ ms. In addition, curve fitting indicated that the curve saturates at $SNR_0 = 876$.



(a)



(b)

FIGURE 2 a) SNR vs. TR curve ($TE = 10$ ms) and b) SNR vs. TE curve ($TR = 4970$ ms) for the standard MRI water phantom. Symbols represent experimental data and solid lines are the fitted curves

Figure 2(b) shows the results obtained from the measurement of SNR as a function of TE for the standard water phantom. As expected, an exponential model of $SNR \propto e^{-TE/T2}$ was successfully fitted to the observed data. The minimum sum of squared difference between the observed and fitted data is achieved when $T2 = 202$ ms.

The results obtained for the standard MRI water phantom thus verify the exponential increase of the T1 (as a function of TR) and exponential decrease of the T2 (as a function of TE) when measured using the routine MRI protocols. T1 for the water phantom is about twice as long as T2, as should be.

The Effects of ρ on the T1 and T2 weighted images of freshly-prepared MRI Slime Phantom

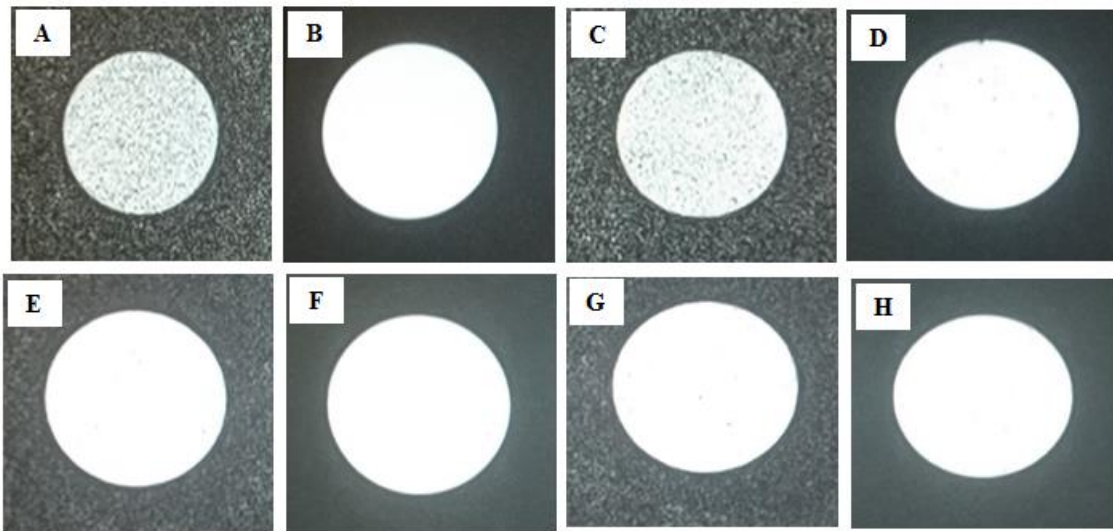


FIGURE 3 Examples of images obtained for all phantoms one day after preparation (as mentioned in text); Left side images: TE = 21 ms, TR = 500 ms, Right side images: TE = 200 ms, TR = 10000 ms

Figure 3 shows the T1 and T2 weighted images of all the slime phantoms obtained from MRI scans 1 day after preparation or TP1. These images were used for SNR determination. From top to bottom, A and B are images of PVA slime phantoms with ρ = of 0.0075 g/ml, C and D are images of PVA slime phantoms with ρ = of 0.0125 g/ml, E and F are images of PVA slime phantoms with ρ = of 0.0175 g/ml and finally G and H are images of PVA slime phantoms with ρ = of 0.0225 g/ml. T2 weighted images display a higher signal intensity as compared to T1 weighted images. Less noisy background can also be seen for T2 weighted images. For T1 weighted images, noise increases for lower ρ while for T2 weighted images, intensity increases with the increase in ρ . T1 and T2 images for TP2, TP3 and TP4 were also obtained for analysis but not shown.

The Effects of ρ on the relaxation and saturation of freshly-prepared MRI Slime Phantom

The T1 curves in Figure 4(a) shows that the SNR of the fresh slime phantoms increases exponentially as TR is increased for all ρ s (TE was fixed at 21 ms). It can also be seen that SNR increases with ρ for all TR values for $\rho = 0.0075\text{g/ml} - 0.0175 \text{ g/ml}$. However, the change in SNR is equal for $\rho = 0.0175 \text{ g/ml}$ and 0.0225 g/ml as indicated by the overlapping of the two curves. However, this change is qualitative and rather subjective. The change is better reported in terms of SNR_o values that were obtained from curve fitting (Table 3) which shows similar trend. The T1 values for all the slime phantoms obtained from curve fitting are shown in Table 2 (See values under TP1). T1 was found to decrease with the increase in ρ from $\rho = 0.075 \text{ g/ml}$ to $\rho = 0.0175 \text{ g/ml}$ but the values are almost the same for $\rho = 0.0175 \text{ g/ml}$ and 0.0225 g/ml . The SNR_o values for all the T1 curves for all ρ s are shown in Table 2 (See values under TP1). Similar to T1, SNR_o decreases with the increase in ρ but starts to level-down for $\rho = 0.0175 \text{ g/ml}$ and 0.0225 g/ml .

Table 2: Saturation (SNR_o) values for all borax concentration (ρ) calculated at different time points

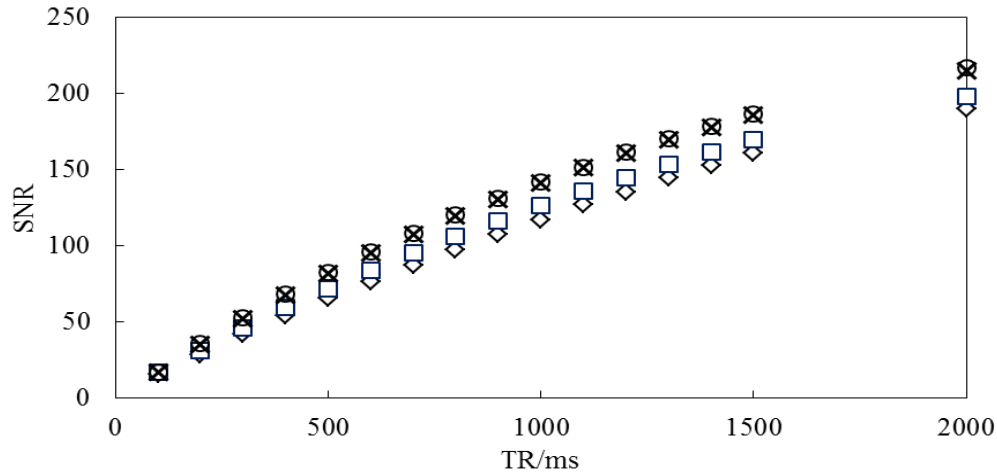
ρ/gml^{-1}	SNR_o			
	TP1 (1 day)	TP2 (7 days)	TP3 (21 days)	TP4 (36 days)
0.0075	352	261	174	177
0.0125	328	267	177	182
0.0175	305	272	192	180
0.0225	304	271	191	176

TP = Time point

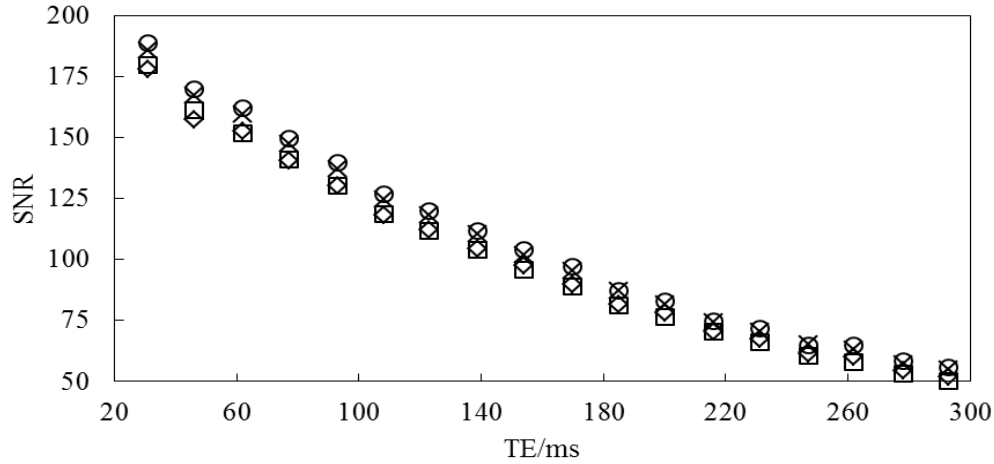
Table 3: T1 values for all borax concentration (ρ) calculated at different time points

ρ/gml^{-1}	T1/ms			
	TP1 (1 day)	TP2 (7 days)	TP3 (21 days)	TP4 (36 days)
0.0075	2389	1343	1232	1387
0.0125	1992	1367	1282	1466
0.0175	1533	1263	1294	1304
0.0225	1541	1249	1283	1284

TP = Time point



(a)



(b)

FIGURE 4 a) SNR vs. TR and b) SNR vs. TE curves for the freshly prepared slime phantoms containing different borax concentrations; 0.0075 g/ml (\diamond), 0.0125 g/ml (\square), 0.0175 g/ml (\circ) and 0.0225 g/ml (\times)

The T2 curves in Figure 4(b) shows that the SNR of the fresh slime phantoms decreases exponentially as TE is increased for all ρ (TR was fixed at 10000 ms) resembling typical T2 relaxation phenomenon caused by spin-spin interaction. However, the SNR values do not seem to differ much for different ρ for all TE values. The T2 values obtained from all the slime phantoms using curve fitting are $T_{20075} = 206$ ms, $T_{20125} = 201$ ms, $T_{20175} = 209$ ms and $T_{20225} = 210$ ms. It can be said that the influence of the change in the microstructure of the mixture on T2 relaxation and T2 values is not as much as on the T1 relaxation and T1 values.

The Effects of Elapsed Time after Preparation on T1 Curve of the MRI Slime Phantom

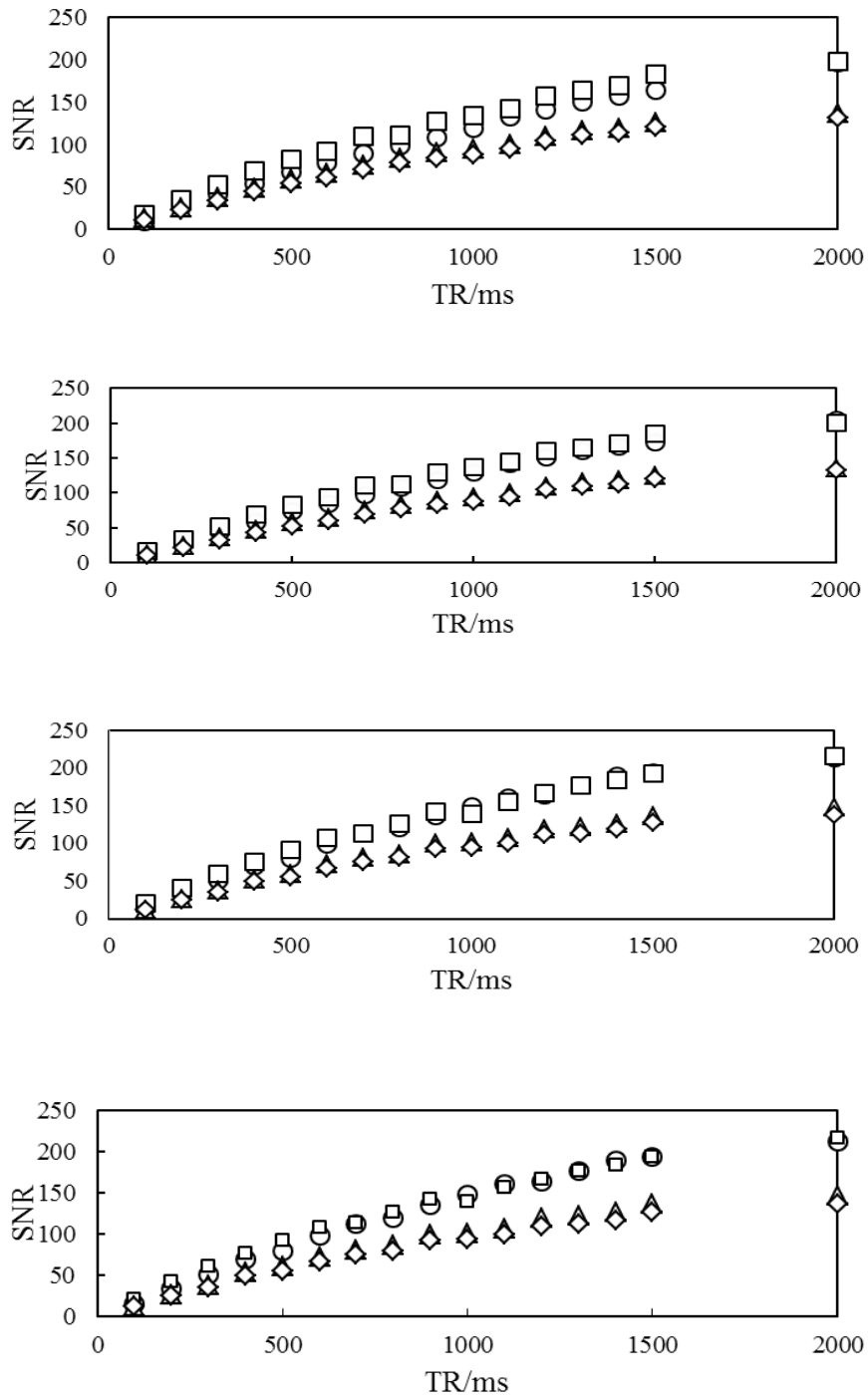


FIGURE 5 SNR vs. TR curves for (from top to bottom) $\rho = 0.0075$ g/ml, $\rho = 0.0125$ g/ml, $\rho = 0.0175$ g/ml and $\rho = 0.0225$ g/ml at TP1 (o), TP2 (\square), TP3 (Δ) and TP4 (\diamond)

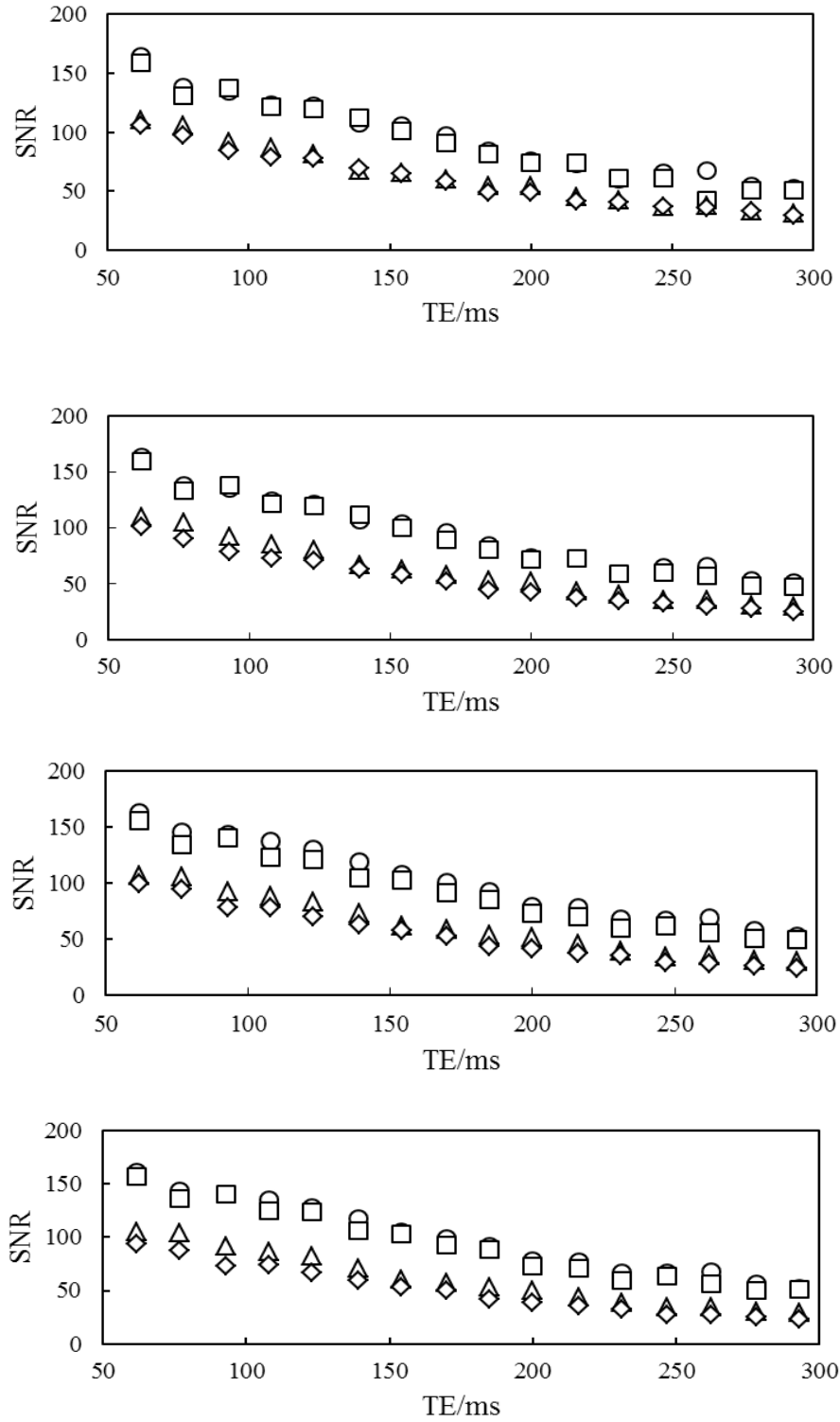
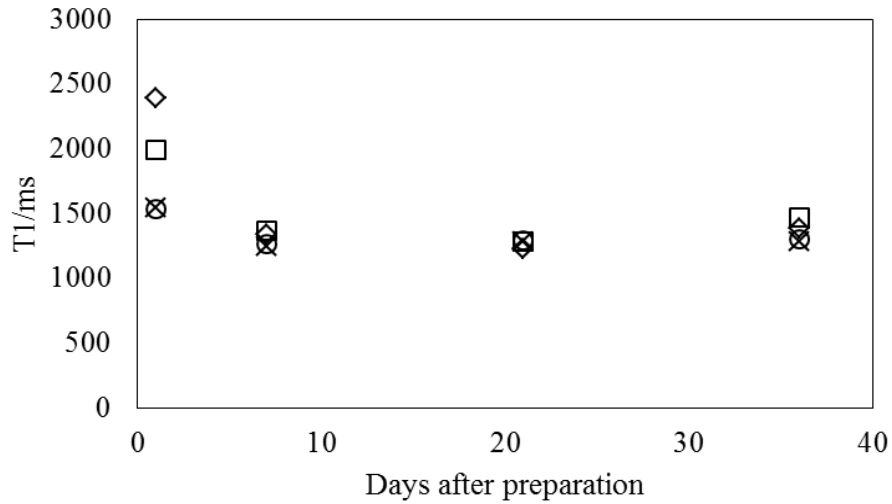
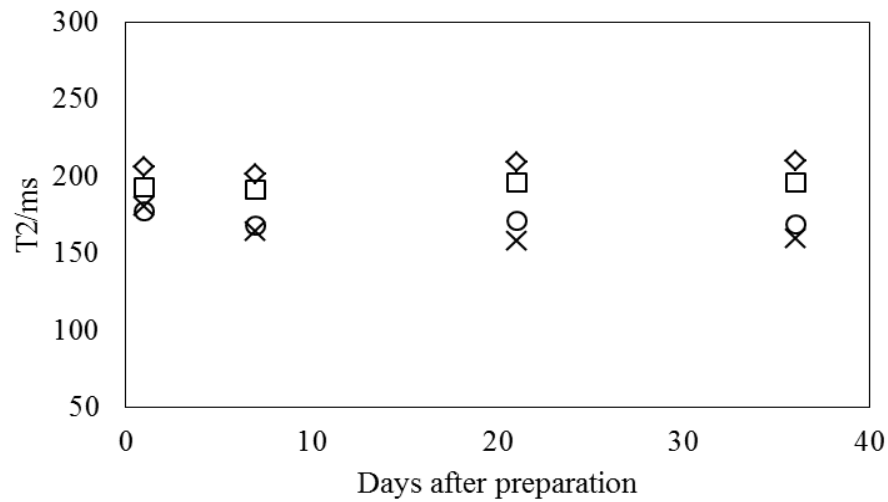


FIGURE 6 SNR vs. TE curves for (from top to bottom) $\rho = 0.0075$ g/ml, $\rho = 0.0125$ g/ml, $\rho = 0.0175$ g/ml and $\rho = 0.0225$ g/ml at TP1 (o), TP2 (\square), TP3 (Δ) and TP4 (\diamond)



(a)



(b)

FIGURE 7 a) Changes in T1 and b) T2 as a function of time after preparation for all phantoms; 0.0075 g/ml (◇), 0.0125 g/ml (□), 0.0175 g/ml (○) and 0.0225 g/ml (×)

Figs. 5 (top to bottom) represent the T1 curves for all the four phantoms respectively. Each figure depicts the T1 curves at different TP. As mentioned in the experimental methods, TP1 = 1 day after preparation, TP2 = 7 days after preparation, TP3 = 21 days after preparation and TP4 = 36 days after preparation. The TE was fixed at 21 ms for all measurements. An exponential increase of SNR as a function of TR is observed for all curves. There is only a small change in SNR from TP1 to TP2 (A slight increase is observed for $\rho = 0.0075$ g/ml). The SNR then dropped to a lower value for all TR values at TP3. The drop is larger at higher TR. The change from TP3 to TP4 is very small or none. The changes observed for all TPs are consistent over all values of ρ .

The Effects of Elapsed Time after Preparation on the T2 Curve of the MRI Slime Phantom

Figure 6 represents the T2 curves for all the four phantoms respectively. Similarly, each figure depicts the T2 curves at different TP. The TR was fixed at 10000 ms for all measurements. An exponential decrease of SNR as a function of TR is observed for all curves. The change in SNR is not observable between TP1 and TP2 as well as between TP3 and TP4. A comparable SNR is however observable between TP1 (or TP2) and TP3 (or TP4) and is relatively larger for smaller TE values, but for TE above 50ms.

The Effects of Elapsed Time after Preparation on the T1 and T2 values

The summarization of results for T1 and T2 values obtained from curve fitting for all phantoms and all TP are tabulated in Tables 2 and 3 respectively and are illustrated in Figure 7(a). A decrease in T1 values for all samples can be seen from 1 day to 7 days after preparation. This could probably due to the loss of water from the mixture during the early days after preparation. At day-7 and onwards, the T1 is less fluctuating and relatively constant. In contrast, the T2 values for all samples are relatively constant for all TPs. The data show a great potential of slime phantoms that are stable and homogenous. Overall, it can also be observed that the T2 value decreases with ρ .

DISCUSSION

The exponential increase of SNR as a function of TR for the MRI water phantom and slime phantoms (figure 1, figure 4(a) and figure 5) is the manifestation of the gradual increase of longitudinal magnetisation with time. This typical T1 relaxation phenomenon resemble spin-lattice energy transfer in which the electromagnetic energy initially absorbed from the radiofrequency (RF) pulse by the spins when they are at resonance is transferred to the surroundings as heat [16]. This transfer of energy can be understood as the behaviour of proton spins seeking equilibrium condition as the RF pulse is switched off. As a result, the net magnetisation in z direction starts to appear in a manner represented by the T1 curve. For a longer TR, the magnetisation in the z direction has more time to regain its magnitude after the RF pulse is given. If TR is sufficiently long, magnetisation reaches saturation (indicated by SNR_o) which can be clearly seen for the MRI water phantom (figure 2(a)). For the slime phantoms (figure 4(a)), TR is not sufficiently long for saturation to be visualised. However, these SNR_o values were able to be estimated by means of curve fitting technique implemented in this study. For the slime phantoms, the values are tabulated in Table 2 for $\rho = 0.0075$ g/ml, 0.0125 g/ml, 0.0175 g/ml and 0.0225 g/ml respectively (See values under TP1). The decrease in SNR_o when ρ is increased shows that SNR_o depends on the composition of the prepared samples particularly on the number of hydrogen protons or the proton density. The MRI water phantom contains higher density of hydrogen protons hence a relatively higher SNR_o . In contrast, the slime phantoms contain a lower concentration of hydrogen protons. Furthermore, hydrogen proton concentration decreases with the increase in borax concentration. As a result, SNR_o shows a decreasing trend with the increase in ρ as shown in Table 2 (See values under TP1). For comparison, SNR was

found to increase with the increase in iron concentration [17].

The T1 values calculated for the freshly prepared samples show similar trend as SNR_o (Table 3 – See values under TP1). T1 is a time constant that is largely influenced by the microstructure of the samples that surrounds the proton spins. Fluids usually have longer T1 which indicates that the proton stays in phase much longer due to the difference in the oscillation frequency between the protons spins and the fluid molecules. Compounds with larger molecules have shorter T1. Their molecules oscillate slower and closer to the precession frequency of the proton spins allowing an efficient energy transfer to the lattice. A significant reduction in the T1 value for the MRI water phantom (T1 = 419 ms) as compared to the standard values for pure water (T1 = 3000 ms) at 3T [18] were due to the addition of NiSO₄ which acted as relaxation modifier, hence shortened the relaxation process.

As shown in Table 3, for freshly prepared phantoms (TP1), T1 decreases with the increase in ρ (decrease in PVA content). Similar trend was reported by a previous study [3] from which T1 values were found to decrease as the concentration of agarose decreases. With the addition of borax, the resulting mixture has caused a change in the local magnetic field inhomogeneity of the proton surroundings especially in the presence of higher ρ . A decrease in T1 means that the longitudinal magnetisation relaxed faster. This could be caused by a faster dissipation of energy to the lattice that has higher ρ . From the results, borax can be said to act as relaxation modifier, shortening the T1 of the slime phantom. It has also caused the saturation to decrease. However, the effects of ρ on T1 and SNR_o ceased for $\rho \geq 0.0175$ g/ml indicating that there is a limit for borax to show its capability as relaxation modifier. Further studies to identify the usefulness of borax as relaxation modifier are necessary.

The decrease in SNR as a function of TE for a fixed TR for the water phantom and the slime phantoms is caused by the gradual decrease in their transversal magnetisation. It can be seen that similar trends of decrease are shown by the water phantom and the slime phantoms but with lower values of SNR at lower TE for the slime phantoms as compared to the water phantom. The higher SNR values for all TE for water phantom are contributed by a higher density of hydrogen protons. Their (water and slime phantoms) T2 values obtained from curve fitting however fall in a small range from 202 to 210 (Table 4). These showed that the prepared slime phantoms have T2 values relatively close to the value for the standard water phantom. Furthermore, the T2 curves are almost incomparable between the slime phantoms as indicated by the overlapping plots (figure 4(b)). Unlike T1 values, T2 values can be said to be less influenced by the microstructure of the samples. The interaction between the proton spins or spin-spin interaction [16] in the slime samples is not differentiated by the small increase in borax concentration. With this knowledge, future study will proceed without the need to re-examine the effects of borax concentration on the transversal magnetisation of the sample.

Table 4: T2 values for all borax concentration (ρ) calculated at different time points

ρ/gml^{-1}	T2/ms			
	TP1 (1 day)	TP2 (7 days)	TP3 (21 days)	TP4 (36 days)
0.0075	206	193	177	180
0.0125	201	191	168	164
0.0175	209	196	171	158
0.0225	210	196	169	159

TP = Time point

From Figs. 5 and 6, the longitudinal and transversal magnetisations for the slime phantoms were found to be affected by the time interval after preparation. From Day 1 to Day 7 after preparation, the change in the T1 and T2 curves is minimal. The change is also minimal from Day 21 to Day 36 after preparation. A marked change is observed between Day 7 to Day 21 after preparation from which the SNR is suppressed to a lower value. This significant reduction can be discussed as due to the evaporation of water from phantoms since water contains an abundance number of hydrogen protons that contribute to the MR signal. Despite the use of para-film to avoid excessive evaporation of water molecules, there was still a small amount of water vapour that managed to get away. In a previous study [19] on nickel-doped agarose/sucrose gels, a slight reduction in signal intensity over the course of 8 weeks was detected. The reduction has been described [20] as due to water evaporation from the phantoms and this will take effect immediately after preparation and could only be stabilized after a long post preparation interval. Sign of stabilization for the slime phantoms in this study can be observed from Day 21 to Day 36 after preparation as the overlapping of the T1 and T2 curves for both TP.

Tables 3 and 4 show the T1 and T2 values for all the slime phantoms at different TPs. The T1 and T2 values obtained from curve fitting are in good agreement with the T1 and T2 values determined in previous studies [5, 7]. Furthermore, the values are relatively constant (with a small fluctuation) as can be seen in figure 7 (a) and (b) especially after 7 days of preparation. This can also be regarded as the sign of stability of the prepared slime phantoms. Therefore, it can be concluded that the slime phantoms prepared in this study do have several potentials to be suggested as MRI phantom and granted further studies.

CONCLUSION

In conclusion, PVA slime phantom does have potentials to be used as MRI phantom as this study demonstrates T1 and T2 values that are measurable using a 3-T MRI system and fall between the T1 and T2 values of various soft tissues e.g. between hundreds of ms to thousands of ms. The consistency of the T1 and T2 values over time especially after 7 days of preparation does reflect the homogeneity and stability of the slime phantoms. However, homogeneity and stability should be quantitatively determined via

a good experimental method and the results are validated so as to represent the true homogeneity and stability characteristics of the phantom. These will be brought over to our future studies. The results obtained from this research were not conclusive as the number of phantoms studied is small with only four time points. Hence, further investigation with larger number of phantoms and more time points are needed.

ACKNOWLEDGEMENT

The authors would like to thank Sollahuddin Omar, for his assistance in the preparation of PVA slime phantom. The authors would also like to express our gratitude to the Biomedical Science Program for the permission to use the equipment for the preparation of slime phantom and the Department of Radiology, Hospital Canselor Tuanku Mukhriz for the permission to use the MRI system. This study was conducted under research grant code of NN-2018-109.

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