The Study of Mechanical Properties and Relaxation Time of Agar Hydrogel for Tissue Mimicking Phantom Material in Magnetic Resonance Imaging

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Abstract. Agar hydrogel is used for tissue mimicking phantom in magnetic resonance imaging studies. The spin-lattice relaxation time, $T_1$, as an important parameter in Magnetic Resonance Imaging measurement was observed. The $T_1$-value represents how fast the net spin magnetization vector recovers to its equilibrium after generation of magnetic field. To explore mechanical properties of agar, shear modulus was examined using a dynamic mechanical analyser. The relation between mechanical properties and spin-lattice relaxation time of agar hydrogel is discussed.

Keywords: hydrogel, agar, magnetic resonance imaging, mechanical properties, phantom

1. Introduction
Magnetic Resonance Imaging (MRI) uses magnetic nature of atomic nuclei for observing and analysing physical and chemical properties of molecules inside a material. When the material is placed inside the magnetic field, the spin of nuclei will align with the field which gives rise to a macroscopic magnetisation and precess with Larmor frequency. The energy transfer between ground state and higher energy level takes place following this rate and energy is emitted when spin returns to its ground state. The signal is detected when magnetisation induces a current in the coil via Faraday induction. It is then processed and reconstructed to be displayed as a spectrum or image.

In MRI study, the properties of material are observed using some parameters, such as spin-lattice relaxation time ($T_1$) and spin-spin relaxation time ($T_2$). The $T_1$ refers to time needed for spins to relax and return toward thermal equilibrium after interaction of spins with magnetic field. $T_1$-value is related with energy dissipated to surrounding environment or lattice and depends on the nature and rate of molecular motion inside the material.

Agar as a tissue-mimicking material for MRI study had been discussed in some studies because of its low cost and easiness to adjust with spin-lattice relaxation rates of human tissues. Several studies had observed $T_1$ properties of hydrogels and found a significant relation between $T_1$-value and hydrogel concentrations [1, 2]. Some studies found that $T_1$ decreases linearly with the increasing agar concentration [1]. Although lower $T_1$ can be achieved by increasing agar concentration, to some extent it is still higher compared to that of some tissues. Therefore, the paramagnetic agent such as CuSO$_4$ is
generally used to further decrease T1 to match the one of corresponding tissues. The previous study showed that T1 of CuSO4 decreased as its concentration increased [1].

In the studies of tissue mimicking phantom, the mechanical properties of agar are observed to determine the compressive force, so that agar could withstand while retaining their shapes. The mechanical properties, such as elastic, viscous and shear modulus were found to be higher as agar concentration increases [3]. In this study, shear modulus which describes the response of material to shear stress is examined.

The effect of agar concentration on shear modulus and spin-lattice relaxation time T1 will be discussed in this study. Agar with various concentrations were measured ca. 2 h after gelation and scanned using MRI to obtain T1. The shear modulus was observed using dynamic mechanical analyser (DMA). The relation between shear modulus and T1 is plotted to explore their link to agar concentration.

2. Materials and methods
Agar powder purchased from local market was mixed with distilled water to form gel. Agar samples were prepared with various concentration of agar mixed with 50 ml distilled water and boiled for 20 min to form 2.5, 5, and 7.5 w/v% of agar gel. The mixture was poured into plastic tube of 57-mm diameter to fill 75 mm height and used without further purification. Agar gel was solidified by putting it in room temperature and scanned after 2 – 4 h of preparation.

The relaxation time measurement was conducted using 1.5 T MRI scanner (Signa, General Electric, US) with spine gradient coil. Samples were arranged according to concentration of agar and CuSO4. Spin-lattice relaxation rate measurement was conducted using inversion recovery spin-echo sequences explained in Hellerbach et.al [4]. In order to assess the homogeneity of sample, four slices were taken from centre of gradient coil in each sample with slice thickness of 5 mm. The parameters used for this study are: repetition time (TR) = 500 – 10000 ms, echo-time (TE) = 10 – 150 ms, field-of view (FOV) = 40 mm x 40 mm, and matrix size = 64 x 64. The images were then analysed using ImageJ to obtain signal intensity and T1 was obtained by fitting the mean signal intensity into TR.

The shear modulus of agar was observed using DMA Mettler Toledo SDTA861. The stress-strain relation curve was plotted to obtain the shear modulus. To explore the relationship between relaxation rates and mechanical properties of agar, spin-lattice relaxation time was plotted against shear modulus.

3. Results and discussion
Table 1 shows T1 relaxation time of various concentration and mixture of agar and CuSO4, showing T1 which decreases as agar concentration increases. The addition of paramagnetic agent such as CuSO4 gives lower T1 and shows the relaxation time which is dependent on CuSO4 concentration. T1-value of agar and agar with CuSO4 are in a good agreement with those in other studies [1] and T1 of human tissue ranging between 500 – 1500 ms at 1.5 T [5]. The lower agar concentration allows more free water protons and results in longer T1. Contrarily, higher concentration of agar gives more barrier and collisions to protons and results in shorter T1. The paramagnetic agent CuSO4, gives even lower T1 and make it a potential material for production of low-T1 tissue-mimicking phantom.

Figure 1 describes the shear modulus of agar hydrogel and shows that shear modulus increases as agar concentration increases. The shear modulus from very low agar concentration cannot be obtained due to broken sample during testing thus sample of 2.5% agar concentration was excluded in our study. The result of shear modulus is consistent with the previous study that showed higher shear modulus due to higher agar concentration [6]. The shear modulus of agar ranges between 130 - 180 kPa for 5% and 300 – 380 kPa for 7.5% of agar concentration. The shear modulus is not significantly affected by addition of CuSO4 as shown in Fig.1 although higher CuSO4 concentration increases the elastic region of agar especially for 5.9% CuSO4.
Table 1. Spin-lattice relaxation time, $T_1$, of various concentration of agar and mixture of agar and CuSO$_4$.

| Sample | Agar concentration (w/v%) | CuSO$_4$ concentration (w/v%) | $T_1$ (ms) | SD  |
|--------|---------------------------|-------------------------------|------------|-----|
| 1      | 2.5                       | 0                             | 1794.713   | 122.187 |
| 2      | 5                         | 0                             | 1540.585   | 220.167 |
| 3      | 7.5                       | 0                             | 1331.503   | 134.376 |
| 4      | 2.5                       | 0.4                           | 1233.339   | 182.094 |
| 5      | 5                         | 0.4                           | 1055.102   | 151.318 |
| 6      | 7.5                       | 0.4                           | 840.336    | 92.270 |
| 7      | 2.5                       | 5.9                           | 1073.836   | 196.888 |
| 8      | 5                         | 5.9                           | 869.565    | 58.776 |
| 9      | 7.5                       | 5.9                           | 740.741    | 87.221 |

Figure 1. Shear modulus of agar and CuSO$_4$. Variation of agar concentration = 5% and 7.5%. Variation of CuSO$_4$ concentration = 0%, 0.4%, and 5.9%. Agar 2.5% was excluded from shear modulus experiment.

The result shows that increasing agar concentration results in lower $T_1$ and higher shear modulus as shown in Figure 2. The plot in Fig. 2 comparatively shows linear relationship between $T_1$ and shear modulus in pure agar as well as mixture of agar and CuSO$_4$, although the addition of paramagnetic agent does not significantly influence shear modulus. The more variation of agar and CuSO$_4$ concentration is needed for further investigation to observe the relation between shear modulus and $T_1$ in order to produce tissue mimicking phantom in MRI with wider range of $T_1$ without neglecting the mechanical properties of material.
4. Conclusion
The study on spin-lattice relaxation time and shear modulus of agar hydrogel had been conducted. Increasing agar concentration results in lower $T_1$ and increasing shear modulus. CuSO$_4$ contributes to even lower $T_1$ for the same agar concentration but does not significantly affect shear modulus.

5. References
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