

# The Effect of Paramagnetic Agent on Relaxation and Mechanical Properties of Agar Hydrogel for Phantom in Magnetic Resonance Imaging

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**Abstract.** Agar hydrogel is largely used in magnetic resonance imaging study as tissue mimicking phantom material for its cost-effectiveness and easy preparation. Spin-spin relaxation time,  $T_2$  is one important parameter in Magnetic Resonance Imaging study. However,  $T_2$  of agar sample is higher than those of human tissues. The addition of paramagnetic agent such as copper sulphate or  $\text{CuSO}_4$  had been observed to match  $T_2$ -value of human tissues. In this study, the effect of  $\text{CuSO}_4$  on relaxation and mechanical properties of agar is observed.

**Keywords:** hydrogel, agar, magnetic resonance imaging, mechanical properties, shear modulus,  $T_2$ , relaxation time,  $\text{CuSO}_4$ , phantom

## 1. Introduction

Agar hydrogel is largely used in magnetic resonance imaging study for tissue mimicking phantom material for its cost-effectiveness and easy preparation. In order to make a material eligible for tissue mimicking phantom material in Magnetic Resonance Imaging (MRI) study, the properties of material must serve some important parameters in MRI, such as spin-lattice relaxation time ( $T_1$ ) and spin-spin relaxation time ( $T_2$ ).  $T_2$  refers to relaxation time of water protons which describes cumulative loss in phase coherence and results in signal decay from each voxel during MRI acquisition. The  $T_2$ -relaxation results from transient magnetic field due to molecular motion and depends on chemical exchange inside the material.

The increasing agar concentration results in lower  $T_2$  although it is relatively high compared to  $T_2$  of some human tissues [1]. The paramagnetic agent is normally added to get much lower  $T_2$  and suitable with  $T_2$  of corresponding tissues. The previous study showed that addition of paramagnetic agents, such as  $\text{CuSO}_4$  and  $\text{Mn}(\text{NO}_3)_2$  reduce  $T_2$  along with increasing concentration of agar or other hydrogels [1, 2]. Several agar hydrogel studies have observed the mechanical properties of agar and showed that increasing agar concentration could increase the mechanical properties of agar hydrogel [3].

In this study the effect of concentration of agar and  $\text{CuSO}_4$  on spin-spin relaxation time ( $T_2$ ) and its shear modulus are discussed. The experiments of agar with various concentrations were measured ca. 2 h after gelation and scanned using MRI to obtain  $T_2$ . The shear modulus was observed using dynamic mechanical analyser (DMA) tool. The relation between shear modulus and  $T_2$  is observed and plotted to explore their link to concentration of agar and  $\text{CuSO}_4$ .



## 2. Materials and methods

The solution of agar hydrogel was formed by mixing agar powder and 50 ml distilled water and boiled for 20 min to form 2.5, 5, and 7.5 w/v% of agar gel. The paramagnetic agent  $\text{CuSO}_4$  was added to agar and distilled water to form concentration of 0.4 and 5.9 w/v% and boiled to form hydrogel. The solution was placed into plastic tube and cooled down to form hydrogel in room temperature. The samples were positioned in such a row and scanned after 2 – 4 h of preparation for measurement of spin-spin relaxation time  $T_2$ .

The MRI experiment to measure  $T_2$  was performed using Carr-Purcell Meiboom Gill (CPMG) sequence in 1.5 T MRI scanner (Signa, General Electric, US) with spine gradient coil. Five slices were taken from each samples. The experiment was performed with parameters: field-of view (FOV) = 100 mm  $\times$  100 mm, matrix size = 64  $\times$  64, repetition time (TR) = 1000 – 2000 ms, echo-time (TE) = 10 – 200 ms, and slice thickness = 5 mm. The image processing and analysis software, ImageJ was used to obtain signal intensity.  $T_2$ -value was obtained by fitting mean signal intensity into TE.

Each sample was cut into 5 mm  $\times$  5 mm  $\times$  1 mm plates for measurement of mechanical properties. The shear modulus of agar hydrogel was observed using DMA Mettler Toledo SDTA861 by varying force load from 1 to 20 N. The shear modulus was acquired by plotting and analysing stress-strain relation curve. The shear modulus of each sample was plotted against  $T_2$  to obtain the relation between relaxation time and mechanical properties of agar hydrogel.

## 3. Results and discussion

Spin-spin relation time  $T_2$  from various concentration of agar and mixture of agar and  $\text{CuSO}_4$  is shown in Table 1. The result shows the decreasing  $T_2$  as agar concentration increases, even less with addition of  $\text{CuSO}_4$ . The value of  $T_2$  in our experiment is comparable to  $T_2$ -value from other experiments [1] and adjustable to  $T_2$  of human tissue from other studies which range between 30 – 100 ms at 1.5 T [4 - 6]. The small reduction of  $T_2$  due to increasing agar concentration shows the effectiveness of increasing  $\text{CuSO}_4$  concentration for reducing  $T_2$  value. As shown in Table 1, the addition of  $\text{CuSO}_4$  affects  $T_2$ -value for the same agar concentration. The reduction of  $T_2$  as a result of increasing  $\text{CuSO}_4$  concentration is up to 50% for 0.4% and only 40% for 5.9w/v% of  $\text{CuSO}_4$ . It shows that the addition of  $\text{CuSO}_4$  yields the maximum reduction in particular range of concentration. The results in this study are relevant with results from other study which found linear reduction in  $T_2$  when agar and  $\text{CuSO}_4$  concentration are increased [1, 2]. The linear reduction of  $T_2$  found in the study is useful in predicting the concentration of paramagnetic agents needed for preparation of tissue-mimicking phantom materials.

**Table 1.** Spin-spin relaxation time,  $T_2$  of various concentration of agar and mixture of agar and  $\text{CuSO}_4$ .

Sample	$\text{CuSO}_4$ concentration (w/v%)	Agar concentration (w/v%)	$T_2$ (ms)	SD
1	0	2.5	116.705	4.119
2	0.4	2.5	51.493	2.770
3	5.9	2.5	32.798	4.630
4	0	5	102.271	18.818
5	0.4	5	50.025	2.538
6	5.9	5	24.149	2.899
7	0	7.5	90.799	44.139
8	0.4	7.5	46.211	2.415
9	5.9	7.5	23.998	2.604

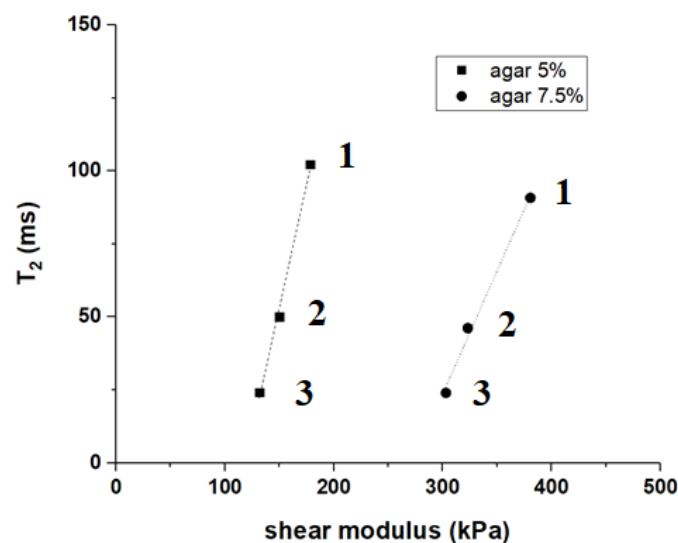
The addition of  $\text{CuSO}_4$  concentration give insignificant contribution to shear modulus in the same agar concentration as described in Table 2. In the experiment of shear modulus, data from 2.5% agar

concentration was excluded due to broken sample during testing. The significant increase was found in higher agar concentration and showed that shear modulus is significantly dependent on agar concentration.

**Table 2.** Shear modulus of various concentration of agar and mixture of agar and CuSO<sub>4</sub>. Agar 2.5w/v% was excluded due to broken sample during testing.

Sample	CuSO <sub>4</sub> concentration (w/v%)	Agar concentration (w/v%)	Shear modulus (kPa)
1	0	5	178.225
2	0.4	5	150.180
3	5.9	5	131.475
4	0	7.5	380.449
5	0.4	7.5	365.749
6	5.9	7.5	302.882

The link between  $T_2$  and shear modulus of agar hydrogel is shown in Figure 1. The addition of CuSO<sub>4</sub> significantly reduces  $T_2$  but insignificantly affects shear modulus. On the contrary, increasing agar concentration significantly increases shear modulus but gives little effect to  $T_2$ -value. The linear relation is found between  $T_2$  and shear modulus and the fitting shows that the slope depends on agar concentration and can be determined with more variation of agar concentration.



**Figure 1.** Shear modulus vs  $T_2$  of agar and mixture of agar and CuSO<sub>4</sub>. 1) Agar + CuSO<sub>4</sub> 0%, 2) Agar + CuSO<sub>4</sub> 0.4%, 3) Agar + CuSO<sub>4</sub> 5.9%. The result from agar 2.5% was excluded in this plot.

#### 4. Conclusion

The effect of adding paramagnetic agent, in our study CuSO<sub>4</sub> to agar hydrogel had been observed. The results show that addition of CuSO<sub>4</sub> results in significant reduction in  $T_2$ -value but insignificant increase in shear modulus of agar hydrogel. The shear modulus is linearly related to  $T_2$ -value along with increasing concentration of agar and CuSO<sub>4</sub>. The study works for limited concentration of agar

and more variation of agar and  $\text{CuSO}_4$  concentration is needed to observe the link between  $T_2$  and shear modulus in agar hydrogel.

## 5. References

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