ASSSESSMENT OF GLYCEROL, GELATIN AND AGAR GELS AS EQUIVALENT MATERIALS FOR MAMMALIAN ORGANS IN PROTON NUCLEAR MAGNETIC RESONANCE IMAGING

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ABSTRACT
The physical NMR parameters of glycerol, gelatin and agar gels have been studied with the view of using them as materials for mimicking mammalian organs. The spin-lattice and the spin-spin relaxation times $T_1$ and $T_2$ respectively for these materials with varied water contents have been measured, using the CXP-100 Brucker NMR spectrometer and the HP-9836 calculator. The results show that the ranges of $T_1$-values are 40-2521 ms, 342-2054 ms and 942-2665 ms for glycerol, gelatin and agar gels, while the ranges for $T_2$-values are 17-1072 ms, 42-1022 ms and 13-433 ms respectively. These values compared with those of mammalian healthy and pathologic tissues having $T_1$-values ranging from 100-1200 ms, and $T_2$-values from 10-180 ms, showed that the ranges of values for the studied materials cover well those of the mammalian organs under the specified working conditions.

INTRODUCTION
The phenomenon of Nuclear Magnetic Resonance (NMR) has been known for many decades and the NMR spectroscopy has been a powerful tool in physico-chemical analysis for almost fifty years. The advent of fast electronics and computers has made it possible in recent years to transform quantified Free Induction Decay (FID) signals of NMR into image by locating these signals and using the analogue reconstruction programmes similar to those used in scanography. Consequently, NMR imaging in certain hospitals has now become one of the most effective, safe and accurate techniques in diagnosis. In order to optimize their performances, NMR imaging machines require periodical quality control just like other imaging machines such as in tomodensitometry, ultrasonography and scintigraphy used in nuclear medicine. Mammalian organs consist of about 75% water on the average. As a result proton NMR gels of gelatine and d’agar, tandis que les gammes pour $T_2$-values sont la mme. 17-1072, 42-1022 mme. et mme. 13-433 respectivement. Ces valeurs ont rivalisé avec ceux des tissus sains et pathologiques mammifères ayant $T_1$-values s’étendant de la mme. 100-1200, et $T_2$-values de la mme. 10-180, prouvé que les gammes des valeurs pour les matériaux étudiés couvrent bien ceux des organes mammifères dans les conditions indiquées de travail.
is used for medical imaging. Thus the quality of the image depends on three major parameters, viz, the proton density $\rho$, the spin-lattice relaxation time $T_1$, and the spin-spin relaxation time $T_2$. To determine or control these parameters, phantoms made of well-defined materials, whose physical and chemical properties are well known are used. Suitable materials for mimicking biological tissues must possess the physical parameters as close as possible to the tissue. The materials should be easily available, cheap, safe and easy to manipulate. The temperature and frequency dependence of the relaxation speed should be of the same order of magnitude as in the mammalian organs.

A number of phantom materials have been suggested and used, varying from divers chemical compositions, organic synthetic polymers, polymeric oxides to suspension of cells and cotton in water, zeolite, glass, clay and divers gel mixtures, whose viscosity is chosen as function of solvent ratio and the $T_1$- and $T_2$- ranges desired. (Inch, 1974$^a$, Derbyshire, (1983)$^b$, Madson et al, (1982). This paper proposes the use of glycerol, gelatin and agar gels as other possible materials in proton NMR imaging. The spin-lattice and the spin-spin relaxation times of these materials have been studied and the results obtained compared with those of mammalian healthy and pathological tissues.

**Instrumentation and Methods**

**Sample Preparation**

The samples used were supplied by MERCK through the company PROLABO in Toulouse, in form of fine powders. The aqueous gels of gelatin and agar were prepared by dissolving the powders in a solution of 1g/litre of methyl benzoic acid in de-ionized water. The solutions were slowly heated to boiling point in order to obtain the required gels. The sample holders previously sterilized by heating, were properly sealed in order to prevent bacteriological growths on contact with air, since these gels are used as media for microorganism cultures. The water content in each case was estimated using the formula

$$P_w = \frac{P_s - P_p}{P_p} \times 100\%$$

Where $P_s$ is the weight of the solvent and $P_p$ the weight of the powder. The values of $P_w$ used in each analyzed sample are contained in table 1. In the case of agar gels, the viscosity becomes very high as the value of $P_w$ decreases, thus introducing inhomogeneity in the samples. Therefore the least convenient value of $P_w$ used was 91%.

**Experimental Set-up**

The experimental set-up is the same as in the normal NMR spectrometry. The machine used for the determination of $T_1$ and $T_2$ was the CXP-100 Brucker Spectrometer at the National Institute for Health and Medical Research, INSERM SC-13, Toulouse, France. The static magnetic field $B_0$ of the spectrometer varies from 0.0 to 1.5T. Measurements for all the samples were made at the ambient temperature of 250°C with $B_0 = 1.0T$, corresponding to a working frequency of 45MHz. The coil round the sample, powered by a radiofrequency generator, served as emitter and receiver of the radiofrequency waves during the irradiation intervals, while the signal was received and amplified at the coil terminals. Data acquisition and treatment for calculating $T_1$ and $T_2$ were done using the Hewlett-Parker HP9836 microcomputer. Inversion recovery method was used for determining the longitudinal relaxation times with the impulse sequence of $\pi t - \pi/2$. The console
allows a free choice of impulse sequence and its duration while the signal is registered using an ADC for the conversion before sending it to the calculator and the curve tracer.

RESULTS AND DISCUSSION

The results of the \( T_1 \) and \( T_2 \) measurements obtained for varying \( P_w \) values in different samples are presented in table 1 and figures 1, 2 and 3. These variations are in good agreement with the theory of relaxation, i.e. \( T_1 \) and \( T_2 \) decrease with increasing viscosity \( (P_w \) increasing) due to the slowing down of the molecular rotation and thus increasing correlation time (Le Bihan, 1985)\(^9\), Vincensini, et al (1982)\(^9\), Neatley, (1978)\(^9\). In order to verify the reproducibility of the sample preparation and measurements, 10 samples of each gel were prepared using glycerol with \( P_w = 80\% \), gelatin with \( P_w = 90\% \) and agar with \( P_w = 98\% \). The dispersion in the measured values are \( T_1 = 1465 \pm 115 \) ms and \( T_2 = 607 \pm 69 \) ms for gelatin giving 8.4% and 11.3% uncertainty in \( T_1 \) and \( T_2 \) respectively. For agar gel, \( T_1 = 1905 \pm 112 \) ms and \( T_2 = 52 \pm 6 \) ms, giving 5.8% and 10.6% uncertainty in \( T_1 \) and \( T_2 \) respectively. For glycerol, \( T_1 = 126 \pm 11 \) ms and \( T_2 = 73 \pm 9 \) ms, giving 8.7% and 12.5% uncertainty in \( T_1 \) and \( T_2 \) respectively.

\( T_1 \) and \( T_2 \) values are used to define NMR tissue equivalence, and the work of Bottoley\(^1\) and the published \( T_1 \) and \( T_2 \) values for healthy and pathologic mammalian tissues (Foster, et al (1984)\(^11\), Cameron et al (1984)\(^12\), Bottomley, et al (1984)\(^1\) Certaines, (1983)\(^7\) form the bases for comparison. Figure 4 presents in summary form, the \( T_1 \) and \( T_2 \) ranges for the different mammalian organs. This figure provides an easy comparison between various materials and tissues. These results show that the relaxation times of the measured samples compared favourably well with those of the mammalian tissues. Glycerol and gelatin gels are suitable for mimicking practically all mammalian tissues since their \( T_1 \) and \( T_2 \) values cover very well those of the tissues. However, the high values of \( T_1 \) in agar gel will limit its applications to mimicking muscles, brain and probably spleen. In general, organs in pathological states have increased values of \( T_1 \) as observed in the case of haematoma, metastasis, meningioma, hepatoma and chronic active hepatitis\(^1\). Consequently, the scope of application of the agar gels could be widened by using them to simulate pathological tissues.

CONCLUSION

Glycerol, gelatin and agar are non-toxic organic materials soluble in water, thus their gels are rich in protons both from these materials as well as from water. The results obtained from the measurements of \( T_1 \) and \( T_2 \) show that the various water contents of the gels prepared, the \( T_1 \) and \( T_2 \) range of values cover well those of the mammalian tissues found in the literature. The upper limit of \( T_1 \) values for each material is quite higher than those obtained in tissues. This observation is desirable especially because \( T_1 \) values are generally higher in pathological tissues than healthy ones. These results also satisfy the recommended conditions for suitable materials for use as NMR phantoms in European countries i.e. \( T_2 = 0.5T_1 \) and that \( T_1 \) should vary from 5ms to a few seconds (COMAC 1986)\(^13\). The preparation and manipulation of these gels are easy and reproducible. All these properties make them suitable materials for mimicking mammalian organs in proton NMR imaging.

ACKNOWLEDGMENT

The author expresses sincere gratitude to Prof. D. Vincensini of the Paul
Table 1: Values of Relaxation times of Glycerol, Gelatin and Agar Gels for various $P_0$ values at ambient temperature, at 45MHz

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Sabatier University, Rangeuil III, Toulouse, France, for permission to use his laboratory facilities and for his cherished pieces of advice.
Figure 1
Variation of relaxation time $T_1$ and $T_2$ in glycerol with water content at ambient temperature and at 45 MHz.

Figure 2
Variation of relaxation times $T_1$ and $T_2$ in Agor geis with water content of ambient temperature and at 45 MHz.
Figure 3
Variations of relaxation times $T_1$ and $T_2$ in gelatine with water content at ambient temperature and at 45 MHz.

Figure 4
Representative Variations of $T_1$ - and $T_2$ - value in diverse mammalian organs from literature.
REFERENCES


