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ASSESSEMENT 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 40-2521ms, 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.

ABSTRAIT
Les paramètres RMN physiques du glycérol, des gels de gélatine et d'agar ont été étudiés avec la vue de les employer comme matériaux pour imiter les organes mammifères. Le tourner-trellis et tourner-tournent le T1 de temps de relaxation et le T2 respectivement pour ces matériaux avec les teneurs en eau diverses ont été mesurés, utilisation du spectromètre RMN de CXP-100 Brucker et de la calculatrice HP-9836. Les résultats prouvent que les gammes de T1-values sont 40-2521ms, 342-2054 mme. et mme. 942-2665 pour le glycérol, gels de gélatine et d'agar, tandis que les gammes pour T2-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 T1-values s'étendre de la mme. 100-1200, et T2-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.

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[1, 2] Kuntz, et al[1], Certaines, 1983. As a result proton NMR

is used for medical imaging. Thus the quality of the image depends on three major parameters, viz, the proton density ρ, 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[3,4].

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[5], Derbyshire, (1983)[6], Madson et al[7], (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

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

Where Ps is the weight of the solvent and Pp 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 Bo 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 Bo = 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 πt-π/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)[8], Vincensini, et al (1982)[9], Neatley, (1978)[10]. 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 ± 115ms and T_2 = 607 ± 69ms for gelatin giving 8.4% and 11.3% uncertainty in T_1 and T_2 respectively. For agar gel, T_1 = 1905 ± 112ms and T_2 = 52 ± 6ms, giving 5.8% and 10.6% uncertainty in T_1 and T_2 respectively. For glycerol, T_1 = 126 ± 11ms and T_2 = 73 ± 9ms, 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[4] 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)[4] Certaines, (1983)[2] 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[11]. 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.

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Table 1: Values of Relaxation times of Glycerol, Gelatin and Agar Gels for various P_w values at ambient temperature, at 45MHz

Glycerol				Gelatin				Agar			
P_w	T_1(ms)	T_2(ms)	T_1/T_2	P_w	T_1(ms)	T_2(ms)	T_1/T_2	P_w	T_1(ms)	T_2(ms)	T_1/T_2
100	2736	2736	1.00	100	2736	2736	1.00	100	2736	2736	1.00
95	2521	1072	2.35	94	2054	1022	2.01	99.8	2665	432	6.17
90	2340	465	5.03	90	1524	662	2.30	99.5	2426	157	15.45
80	1885	313	6.02	85	1271	362	3.52	99.0	2226	90	24.73
70	1335	255	5.21	80	1457	385	3.75	98.5	2076	65	31.94
60	962	192	5.01	75	936	216	4.33	98.0	1802	47	38.34
50	590	152	3.88	70	1130	262	4.31	97.0	1663	35	47.51
40	449	111	4.05	65	739	119	6.21	96.0	1489	25	59.56
20	123	73	1.68	60	827	149	5.55	95.0	1354	24	56.41
0	40	17	235	55	678	126	5.38	94.0	1320	22	60.00
				50	599	85	7.05	93.0	1288	18	71.56
				45	488	67	7.28	92.0	1106	18	61.44
				40	445	63	7.06	91.0	942	13	72.46
				35	469	60	7.82				
				30	382	54	7.07				
				25	321	44	7.30				
				20	324	42	7.71				

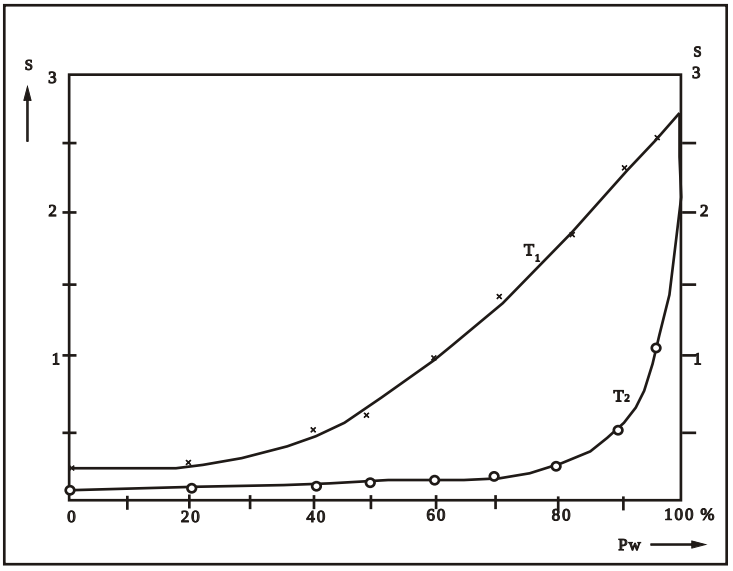

Figure 1
Variation of relaxation time T1 and T2 in glycerol with water content at ambient Temperature and at 45 Mhz.

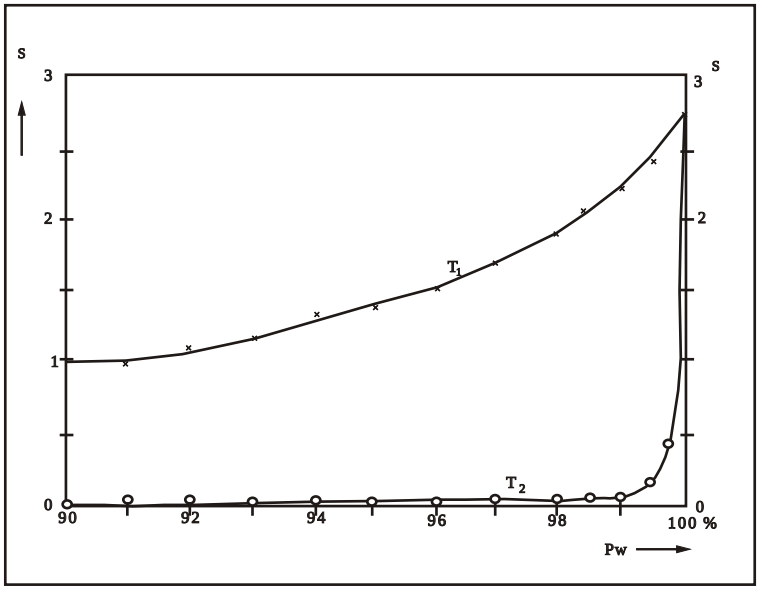

Figure 2
Variation of relaxation times T_1 and T_2 in Agor geis with water content of ambient temperature and at 45 MHz.

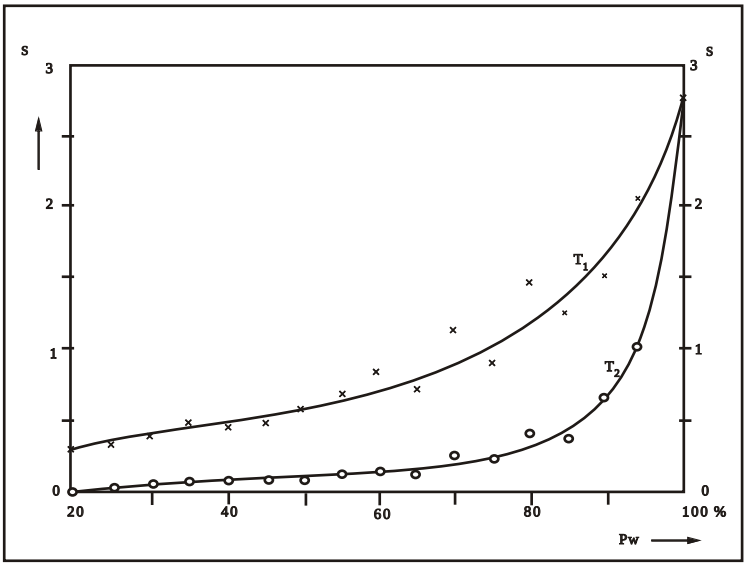

Figure 3
Variations of relaxation times T_1 and T_2 in gelatine with water content at ambient temperature and at 45 MHz.

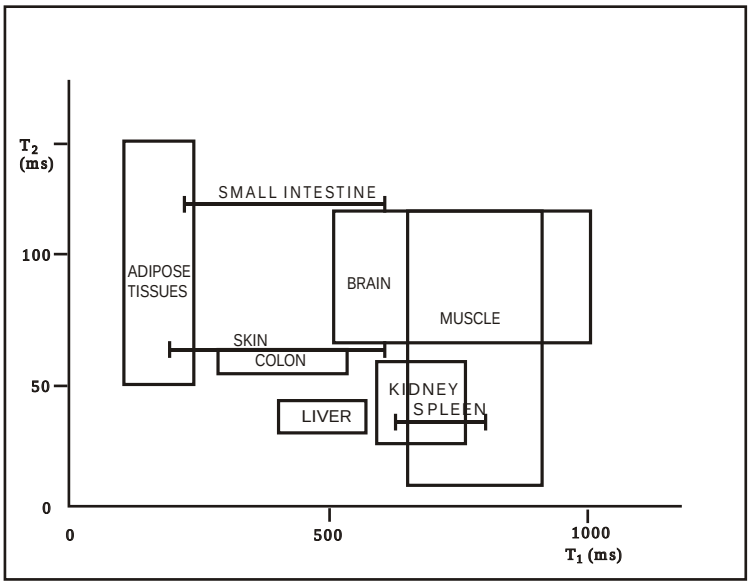

Figure 4
Representative Variations of T_1 - and T_2 - value in diverse mammalian organs from literature.

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