^{23}Na Nuclear Magnetic Relaxation Times in Pig Tissue

Ulrich Brändle, Elmar Kammerer, Doris Köhnlein, and Otto Lutz *
Physikalisches Institut der Universität Tübingen

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Longitudinal relaxation times T_1 and linewidths of ^{23}Na have been measured in the following tissues of pig: lung, heart, kidney, spleen, liver, and muscle. T_1 shows typical values between 12 ms and 25 ms, suitable values for ^{23}Na NMR imaging.

NMR imaging with protons is now a well known method with an increasing amount of applications. Imaging with other nuclei, like ^{23}Na, is also in the discussion [1] but will be relatively difficult due to its receptivity of $9.3 \cdot 10^{-2}$ relative to that of ^{1}H at constant magnetic field. Further, ^{23}Na is much less abundant in tissue than water protons. With regard to the sensitivity a further factor of about 10^{-3} has to be taken into account.

So it is not surprising that as far as we know, only one paper with a ^{23}Na image has been published [2]: the heart of a rat is presented.

The signal intensity in NMR imaging depends not only on the density of the nuclei observed, but also on the relaxation times T_1 and T_2, and the radiofrequency pulse sequence and shape. It is obvious that the knowledge of the relaxation times is very important. Only a few relaxation times T_1 of ^{23}Na in tissue of animals have been reported: T_1 lies between 12 ms and 20 ms in rat brain and muscle [3], frog muscle [4], rat muscle [5] and normal and cancerous rat tissue [6].

In the following we report on measurements of T_1 and the linewidth of ^{23}Na in different tissues of pig.

The T_1 measurements of ^{23}Na were performed at 23.81 MHz (2.11 T) by the Fourier transform inversion recovery method following the procedure described for ^{25}Mg in [7]. A Bruker pulse spectrometer SXP4-100, an externally NMR stabilized Bruker 38″ magnet system, and a B-NC 12 data unit were used. The temperature was (299 ± 1) K. Non rotating samples with 10 mm diameter and filling heights of 10 mm have been used.

* Reprint requests to Prof. O. Lutz, Physikalisches Institut der Universität Tübingen, Auf der Morgenstelle 14, D-7400 Tübingen.

Some samples for informative measurements originated from a butcher's shop and have been measured some hours after slaughtering. Later on, the samples have been obtained from an abatoir. So it was guaranteed that the different tissues were from the same animal and the measurements could be started shortly after death. The measurements have been completed within two days.

Results

In Fig. 1, a stagged plot of a T_1-measurement of ^{23}Na in a piece of heart of about 0.7 cm^3 is presented. Since T_1 is relatively short, around 20 ms, a rather high pulse repetition rate can be used, a promising feature for NMR imaging. Signal-to-noise ratios of typically 100 : 1 can be obtained in the different tissues within 50 seconds using 500 FID's for an individual spectrum.

For different animals, T_1 values of heart tissue are as follows (in ms): (19.1 ± 0.3), (19.4 ± 1.3), (20.0 ± 0.5), (21.1 ± 0.2), (22.0 ± 0.2) and (22.8 ± 0.7).

Each value is the mean of 3 to 5 measurements. (The largest value dates from a very young pig.) From this row one derives that the variation of T_1 between different animals is relatively small.

In Table 1, the results of measurements for 3 different animals are presented. The shortest T_1 is found in liver, the longest in muscle tissue, where the T_1 values differ by a factor of 2 between these tissues. Spleen, kidney, heart, and lung have typical T_1-values in the range between those of liver and muscle. The results of an investigation of T_1 of protons in pig tissue [8] show a very similar behaviour.

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Table 1. Measured longitudinal relaxation times T_1 (with the statistical errors from 5 individual T_1 measurements) and measured linewidths $\Delta\nu$ of ^{23}Na in different pig tissues. The linewidths are partly affected by the homogeneity of the magnetic field, therefore no error is given. The T_2 values, calculated from the linewidths according to $T_2 = 1/\pi\Delta\nu$ are also listed.

Tissue	Pig 1			Pig 2			Pig 3		
	T_1/ms	$\Delta\nu$/Hz	T_2/ms	T_1/ms	$\Delta\nu$/Hz	T_2/ms	T_1/ms	$\Delta\nu$/Hz	T_2/ms
Lung	22.4 ± 0.2	102	3.1	–	–	–	21.1 ± 0.2	102	3.1
Heart	21.1 ± 0.2	48	6.6	22.8 ± 0.7	40	7.9	22.0 ± 0.2	50	6.4
Kidney	15.6 ± 0.7	51	6.3	–	–	–	15.1 ± 0.3	52	6.2
Spleen	15.5 ± 0.4	55	5.8	–	–	–	15.1 ± 0.2	54	5.9
Liver	11.5 ± 0.2	62	5.1	12.0 ± 0.4	56	5.7	12.8 ± 0.1	57	5.5
Muscle (fatty)	–	–	–	24.8 ± 0.2	43	7.4	–	–	–
Muscle	–	–	–	20.7 ± 0.5	38	8.3	–	–	–

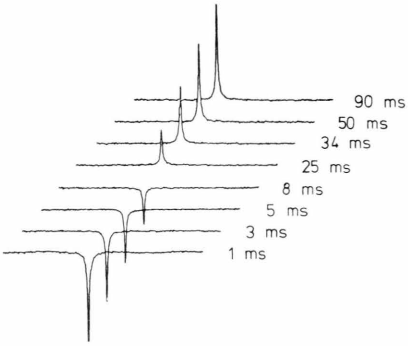

Fig. 1. Stagged plot of a T_1-measurement of ^{23}Na in heart tissue of pig: $T_1 = 21.3$ ms. Each line was obtained by 1000 free induction decays after the 90° pulse of the FT inversion recovery sequence within 100 s. The τ-values are given in the figure, the presented spectrum width is 5200 Hz.

The signal intensities in the tissues investigated are clearly very different due to the varying ^{23}Na contents.

Although the line widths of the nonrotating samples are somewhat affected by the homogeneity of the magnetic field, it is obvious from Table 1 that strong differences occur. The smallest line widths are found for muscle tissues and heart, a special muscle tissue. Very interesting is the fact that in lung very broad ^{23}Na NMR lines with about 100 Hz have been observed, although the T_1 is rather long. If one calculates T_2 from the linewidths, as given in Table 1, the strong difference between T_1 and T_2 is clearly revealed. This fact is well known from earlier measurements for other animal tissue [4, 5]. But for a detailled comparison, T_2 should be measured directly. Such investigations are in progress.

Summarizing, in pig tissue, ^{23}Na has suitable spin-lattice relaxation times T_1 for rapid data acquisition and a large range of T_1, T_2, and sodium contents for achieving a good contrast in ^{23}Na NMR imaging.

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