Temperature Measurement Using the ^{129}Xe Chemical Shift

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Introduction

The temperature dependence of the chemical shift of the ^{129}Xe resonance was examined to explore its usefulness for measuring tissue temperature. In vitro studies using a 4.7 T scanner showed that the ^{129}Xe resonance varies by 0.25 ppm/ degree C in lipid samples (corn oil, olive oil and octanol), and there is no significant shift in aqueous solutions (Figure 1). By contrast, the proton resonance varies by only 0.01 ppm / degree C in water, while the proton resonance in lipids displays no significant temperature-shift (1,2) (Figure 2). Our experiments suggest that the ^{129}Xe resonance can be used for measuring the temperature of tissues with a high lipid content (e.g., breast or subcutaneous fat) and serve as a temperature insensitive internal reference for measuring water proton resonance.

Methods

Cylindrical glass ampoules of 80 ml volume were filled to 45 ml with the liquid of interest. A hollow glass protrusion, or "cold finger", extending from the ampoule, was cooled by submersion in liquid nitrogen. Xenon, of natural isotopic abundance (26% ^{129}Xe), was condensed into the cold finger, the ampoule was sealed, and the xenon was allowed to evaporate and dissolve into the liquid. The pressure in the ampoule was about 2.5 atm. The sample temperature was varied by means of an air cartridge heater, and an electronic temperature controller attached to an RTD probe. The xenon experiments were performed on an Omega 4.7 T spectrometer, the resonance frequency measured using a standard FID one-pulse sequence, employing 512 averages (bandwidth 30 kHz). Chemical shift values were referenced to the ^{129}Xe gas phase signal, which was assigned a value of 0 ppm.

Proton chemical shift was measured in a porcine liver sample using a 1.5 T scanner (GE Signa) with an EPSI technique (TR 350 ms, spectral bandwidth 767 Hz). The temperature of the sample was varied using a thermo-bath, monitored with a thermocouple.

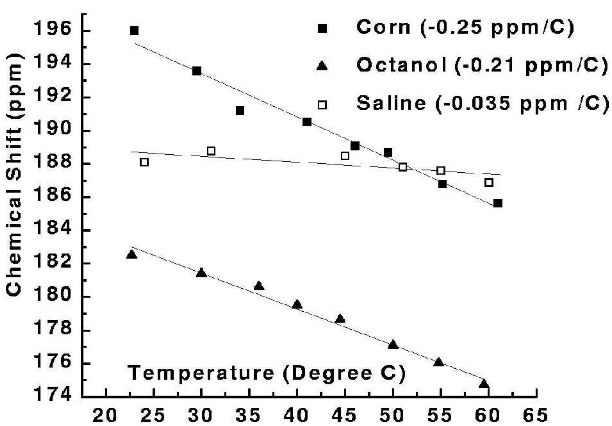

Figure 1: ^{129}Xe chemical shift variation with temperature.

Results

The oils studied revealed a strong variation of the ^{129}Xe chemical shift with temperature (Figure 1). The variation was about 0.25ppm/degree C for corn oil, 0.21ppm/degree C for Octanol, and 0.21 ppm/ degree C for Olive oil. Xenon dissolved in saline displayed a negligible temperature shift (Figure 1). The proton resonance frequency in lipids displays no temperature shift (0.001 ppm/degree C) and the proton resonance in aqueous solutions displays a temperature shift of 0.01 ppm/degree C (Figure 2).

Discussion

In an MR system with multi-nuclear capability, a combination of ^{129}Xe and proton MR could be used to track the temperatures obtained in hyperthermal tumor ablation therapies, such as focussed ultrasound. The thermal shift of the ^{129}Xe resonance could be used to monitor temperature changes of lipid tissues using the proton resonance in the same tissue as an internal reference. In aqueous tissues, the proton chemical shift could be used to monitor the temperature with the ^{129}Xe resonance as the internal reference.

Xenon is lipophilic, with a partition coefficient of ~2 in common lipids. NMR spectroscopy in live rats breathing hyperpolarized ^{129}Xe (which has a nuclear magnetization of about 20,000 fold greater than that of thermally polarized ^{129}Xe) have identified resonances from the fat tissues in the thorax and the brain (3,4). Hyperpolarized xenon, dissolved in media such as perfluorocarbon emulsions or intralipid suspensions, could be directly injected into the tissue of interest (5).

Recently ^{129}Xe spectra have been obtained from GH3 and RIF-1 tumors in rats after injection of the tumor using hyperpolarized xenon dissolved in perfluorocarbon emulsions and saline (6). Hyperthermal treatment of tumors could be monitored using ^{129}Xe MRI.

To obtain an understanding of the mechanism of the ^{129}Xe temperature shift, ^{129}Xe NMR was performed on oil samples of different viscosities. The chemical shift displayed a linear relationship with the logarithm of the viscosity (slope of 6 ppm/log(centipoise)). Viscosity decreases with an increase in temperature, which is in the same direction to that of the temperature shift of ^{129}Xe in lipids. The mechanism of the temperature shift of ^{129}Xe in lipid is probably different than that of proton in water. Because of the small size of the electron cloud of the ^{1}H nuclei, the resonance frequency of protons are sensitive to the strength of the hydrogen bonds. The huge electron cloud of xenon, however, seems to be far more sensitive to the electric multi-poles of the lipid chain than to the dipoles of the water molecules.

In conclusion, the temperature sensitivity of the chemical shift of the ^{129}Xe resonance, in lipids, could be used to monitor temperature variations in such interventional procedures that induce hyperthermia, as in the treatment of susceptible tumors.

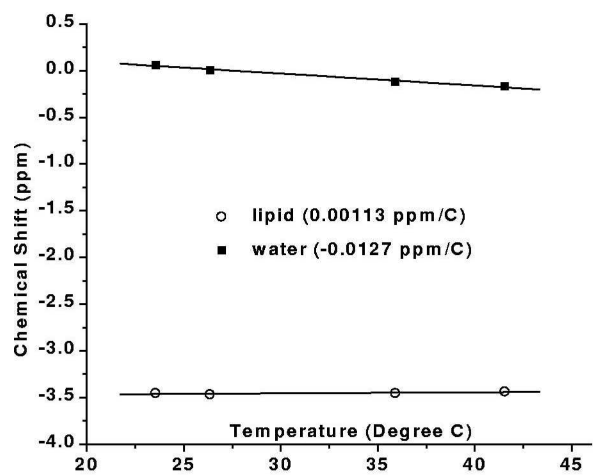

Figure 2: Proton chemical shift variation with temperature.

References

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