^{1}H NMR chemical shift selective (CHESS) imaging

Technical note

¹H NMR chemical shift selective (CHESS) imaging†

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1. Introduction

¹H NMR images of human or animal tissues reflect the spatial distribution of both water (H_2O) and methylene (CH_2) proton resonance signals. There are several reasons for a separation of these contributions: (i) the large chemical shift dispersion in high magnetic fields ($\geqslant 1.5$ T) which leads to an apparent spatial shift in 'composite' images between the superimposed H_2O and CH_2 images; (ii) the evaluation and interpretation of proton H_2O and CH_2 relaxation times from NMR images; and (iii) the physiological implications of 'water' and 'fat' distributions for medical diagnosis. Here we describe a chemical shift selective (CHESS) imaging technique which destroys the unwanted signal component by means of a selective 90° excitation pulse and a subsequent magnetic field gradient ('homogeneity spoiling gradient') prior to imaging of the wanted component. The new method allows the creation of either a pure 'water' or 'fat' image.

In general, water and methylene proton resonances can be distinguished by their relaxation times (T_1, T_2) and chemical shifts, i.e. their exact NMR resonance frequencies which differ by about 3 PPM. Since *in vivo* spin–lattice relaxation times T_1 of adipose tissues are often shorter than values for other tissues (Bottomley *et al* 1984a), a reasonable suppression of the 'fat' contributions can be achieved by using an inversion-recovery imaging technique and adjusting the inversion–recovery delay to the respective zero-crossing time. Obviously the method is applicable to any imaging magnet independent of homogeneity and field strength, but it will fail in those cases where the T_1 values of the CH_2 resonances are similar to the T_1 values of certain water resonances. In cases where high magnetic field strengths and homogeneities of the order of 1 PPM are available, a true biochemical discrimination of H_2O and CH_2 images based on their chemical shift difference will be superior. A first approach of this kind has recently been proposed (Bottomley *et al* 1984b) using selective saturation of the unwanted resonance immediately before application of a conventional NMR imaging sequence. Direct selective excitation of the resonance frequency of the wanted component prior to imaging has only been described for imaging without plane selection (Hall *et al* 1984). In such cases the dual problem of selection of NMR frequencies and spatially encoded frequencies is easily circumvented by replacing the slice selection pulse by a chemical shift selective pulse within the imaging sequence.

2. Method

The new CHESS imaging technique presented here relies on a single frequency-selective excitation pulse with a flip angle of 90° followed by a dephasing gradient ('homogeneity

spoiling gradient'). The procedure leaves the spin system in a state where no net magnetisation of the unwanted component is retained while the wanted component remains entirely unaffected in the form of z-magnetisation. We have used a 10 ms RF pulse with a Gaussian shape and a 20 ms period for application of the spoiling gradient for which it is convenient to use the slice selection gradient of the subsequent imaging sequence. A schematic pulse and gradient sequence of the CHESS imaging technique using the spin-warp modificatin of 2D Fourier imaging is presented in figure 1. Experiments have been carried out using a 2.3 T magnet with a clear bore of 40 cm (Bruker BNT-100).
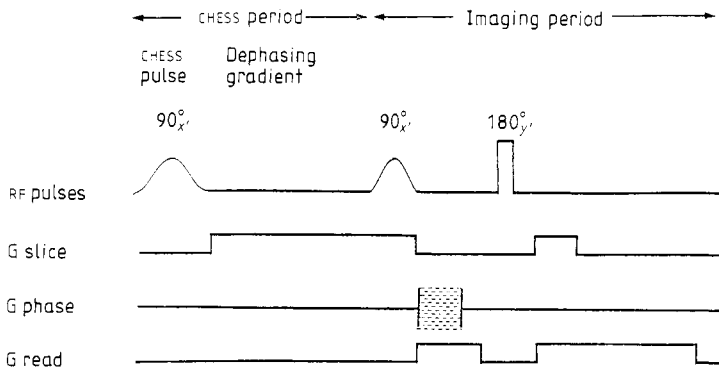

Figure 1. Schematic diagram of the CHESS imaging sequence.

3. Results

To demonstrate the action of the CHESS period we have recorded ^{1}H NMR spectra of a human hand at 100 MHz. The top spectrum in figure 2 is a conventional ^{1}H NMR spectrum displaying H_2O and CH_2 proton resonances. It has been obtained by Fourier transformation of the time-domain signal recorded after application of a single non-selective 90° RF pulse. In the middle spectrum the H_2O resonance has been eliminated by a CHESS period prior to the 90° RF pulse. The irradiation frequency of the CHESS pulse has been adjusted to the H_2O resonance frequency. The bottom spectrum shows the corresponding experiment on the CH_2 resonance. It should be noted that the CHESS period provides a result similar to that of a burst of saturation pulses. In contrast to saturation conditions, however, the transverse magnetisations are coherently dephased and thus may be recalled by means of appropriate refocusing.

The four 100 MHz ^{1}H NMR images of a human hand shown in figure 3 represent two transverse cross sectional slices through the metacarpalia (a, b) and two palmar slices at the metacarpophalangeal joints (c, d). The CH_2 images shown in figures 3(a) and 3(c) demonstrate that the CH_2 signals stem from the lipids within the bone marrow, the subcutaneous fat and fat surrounding muscle groups and tendons. The H_2O images shown in figures 3(b) and 3(d) show water signals from muscle tissue, bone marrow, blood and synovial structures. It is interesting to note that the H_2O images generally seem to provide more structural details than normal 'composite' images. For example, the H_2O image (figure 3d) clearly delineates the joint space arising from synovial water content. In fact, this information is lost in 'composite' images by overlap with spatially shifted CH_2 signals from bone marrow.
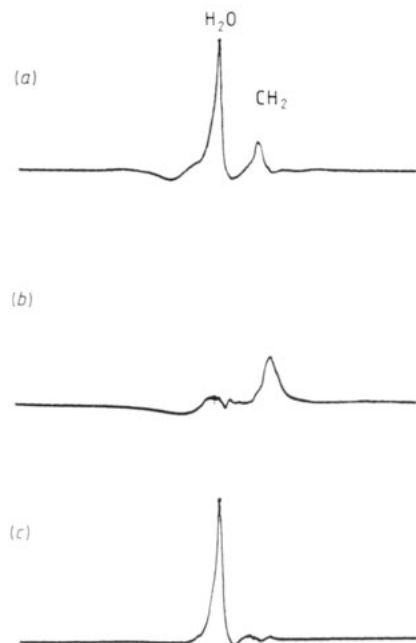
Figure 2. 100 MHz ^{1}H NMR spectra of a human hand. (*a*) Normal spectrum obtained after application of a single 90° excitation pulse; (*b*) CH_2 spectrum obtained by selective elimination of the H_2O resonance using a CHESS period prior to the 90° pulse; and (*c*) corresponding H_2O spectrum with a CHESS period applied to the CH_2 resonance.
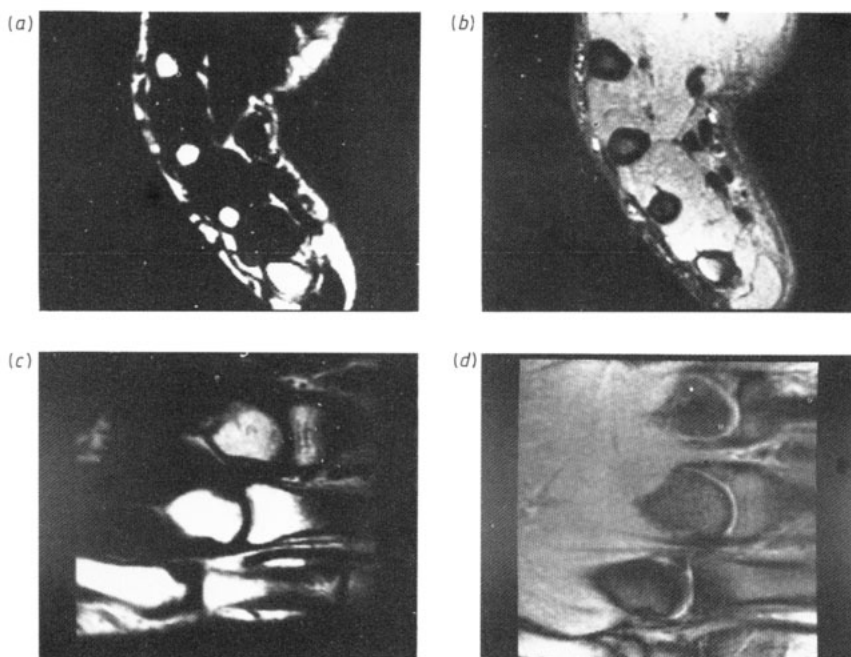

Figure 3. 100 MHz ^{1}H NMR images of a human hand with a resolution of 0.5 mm and a slice thickness of 3 mm. (*a*) CH_2 image of a transverse cross section through the metacarpalia; (*b*) corresponding H_2O image; (c) CH_2 image of a palmar cross section at the metacarpophalangeal joints; and (*d*) corresponding H_2O image.

4. Conclusions

The CHESS imaging strategy bears the following advantages.

(1) It provides chemical shift images without the considerable demand on measuring time as for three-dimensional chemical shift imaging techniques (Pykett and Rosen 1983).

(2) It is simple and allows combination with any imaging sequence (e.g. inversion-recovery sequences) as well as easy implementation on any high-field NMR system with magnetic field homogeneities of the order of 1 PPM.

(3) It needs only a single imaging experiment to obtain either a H_2O or CH_2 image and allows subsequent reconstruction of a 'composite' image without distortions due to chemical–spatial shifts.

(4) Only negligible RF power is needed in addition to the conventional imaging sequence.

(5) Gating of the imaging experiment remains possible.

(6) The method is applicable to imaging of other nuclei.

Human studies using whole-body NMR imaging systems are in progress (Matthaei *et al* 1985).

References

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