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In vivo ^{1}H-MR spectroscopy of the human heart

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1. Introduction

Obtaining ^{1}H-MR spectra of the human heart in vivo is of particular interest for two reasons: first because of the potential to study the lipid metabolism which is of special interest in the heart, and second, because invasive animal and human studies have indicated that total Cr content is reduced in the failing heart [1,2]. Proton magnetic resonance spectroscopy (^{1}H-MRS) might therefore be useful for diagnosis and monitoring of treatment of chronic heart disease. However, as ^{1}H-MRS is much more sensitive to motion than ^{31}P-MRS, reproducible ^{1}H-MRS is very difficult to establish for the working human heart.

There are only a few reports in this field. Den Hollander et al. [3] have used cardiac triggered CSI and single voxel techniques to determine lipid distributions in and around the human heart, and Bottomley and Weiss [4] have applied cardiac triggered STEAM to acquire single voxel spectra in healthy and infarcted myocardium for the determination of total Cr content. In our own experience [5,6], it has turned out that it is necessary to not only synchronize MRS with the motion of the heart, but also with respiration, because the heart moves as much as 5 cm with respiration. Such large displacements do not only lead to strong variations in signal phase, but also to severe degradation in shim quality, resonance offset, water suppression efficiency, and -worst of all-severe alteration of tissue content of the region of interest (ROI). Different methods of double triggering have been implemented and tested, and inter- and intrasubject variability using double triggering has been studied.

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2. Materials and methods

2.1. Acquisition parameters

Experiments were performed on a standard 1.5 T GE SIGNA system using a surface receive coil. An optimized PRESS sequence was used for localization (TE 20 ms, 64–256 acquisitions, outer volume suppression, with and without water presaturation). For standardization a separately recorded TE decay of the unsuppressed water signal was used. The oblique ROI (4–6 cm^3) was aligned along the septum. Flip angle determination, shimming and water suppression optimization was done with the same triggering methods as for spectrum acquisitions. For ECG acquisition a home-built ECG sensor [7] was used.

2.2. Double triggering methods

Three methods of respiratory/cardiac triggering were examined: In method A, the volunteer enabled ECG-gated acquisitions towards the end of each expiration period by pushing a pneumatic bulb. In method B, the respiratory trigger was derived from monitoring air pressure in the in- and expired air. A home-built electronic circuitry enabled one ECG triggered MR acquisition when zero air flow was detected. (Fig. 1). For method C (Fig. 2), we used the fact that the amplitude of the ECG depends on respiration and the rotation of the heart [8], i.e. the position of the heart can be monitored with the ECG signal alone with an adequate positioning of the ECG electrodes. The ECG trigger was enabled only if the QRS amplitude was in a narrow range defining expiration.

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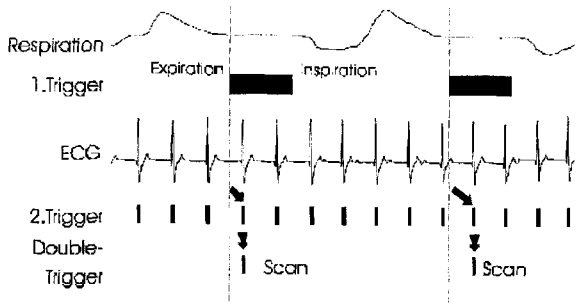

Fig. 1. Experimental scheme for combined respiratory/cardiac triggering based on pressure differences in inhaled and expired air (Scheme B).

Subjects: Relative merits of the different triggering methods have been studied in over 40 examinations in 17 subjects mostly using the unsuppressed water signal. Reproducibility was established for method C in a ^{1}H-MRS study comprising two independent examinations in each of nine subjects.

3. Results and discussion

3.1. Double triggering

Since the motion of the diaphragm is smallest during expiration [8], all respiration triggering was done in expiration. ECG gating alone was not adequate to stabilize the MR signal sufficiently to allow for satisfactory shimming, water suppression and spectra acquisition. With ECG gating alone, the variation of the unsuppressed water signal was typically 4% and 30° for signal magnitude and phase, respectively. This reduced to 2% and 11° with method B.

Working with motivated volunteers, all three methods gave spectra of acceptable SNR. Method A was abandoned, because it demanded a very high level of concentration and body control. In addition the position of the heart was not reproducible enough, possibly because pushing of the pneumatic bulb introduced small motions of the whole body.

Method B gave good results and demonstrated overall an excellent inter- and intra-individual reproducibility. However, it was noted that some single acquisitions were off, even though the double-trigger was at the desired time point in the respiration cycle. A rationale for this could be that the monitored air flow is always zero when the subject stops breathing, irrespective of the position of the diaphragm and consequently the heart.

The position of the diaphragm/heart is under more direct control with method C. This method has the drawbacks that it is sensitive to the positioning of the electrodes, which must be optimized to show a large respiration-related ECG amplitude modulation. The spectra obtained with this method are comparable to those of Method B.

Method C is the method of choice for patient examinations, because only the ECG is needed, whereas for Method B the subject is required to wear a mask. For all methods, it is important that the subjects are relaxed. Tension can prevent reproducible respiration.

3.2. Reproducibility

The quality of cardiac ^{1}H-MR spectra recorded with method C and their intrasubject reproducibility is demonstrated in Fig. 3. For most subjects good spectral quality was achieved and could be reproduced in a second exam (subject A in Fig. 3). For some cases ($\sim$ 25%), however, spectral quality (stability of signal and/or shim) was clearly inferior in one or both exams (subject G in Fig. 3).

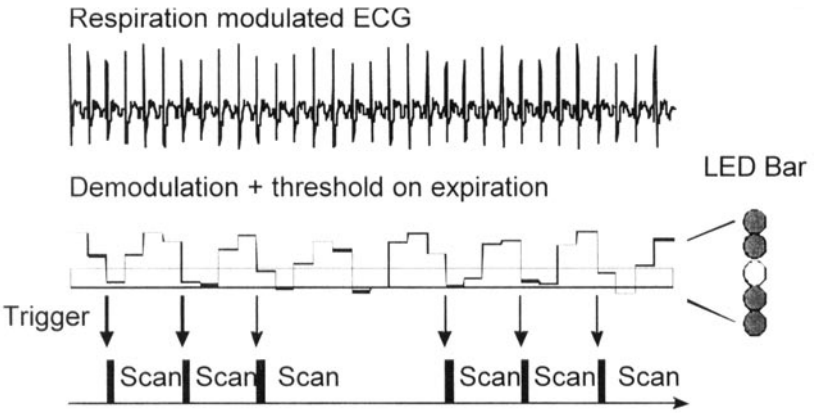

Fig. 2. Experimental scheme for combined respiratory/cardiac triggering based on respiration-related amplitude variations of the ECG signal (Scheme C).

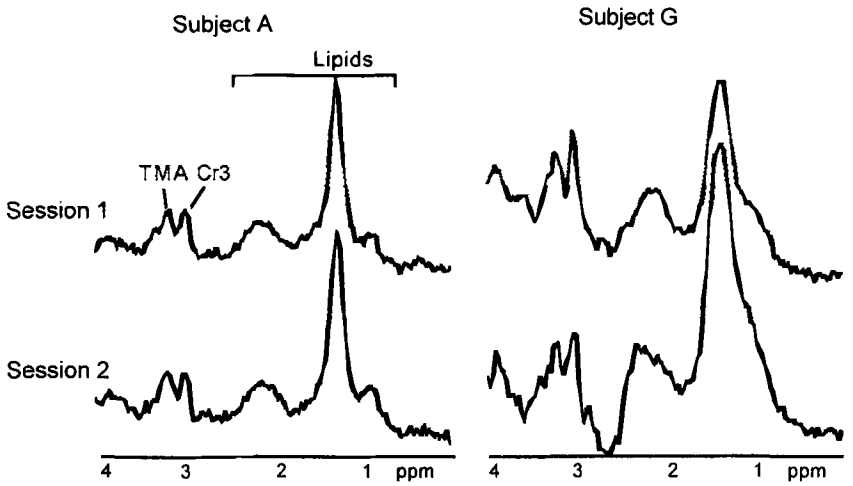

Fig. 3. ^{1}H-MR spectra of the human heart (septum) recorded with double triggering (method C) in two independent sessions and two subjects.

3.3. Metabolites

The recorded ^{1}H-MR spectra of the human heart contained contributions from creatine (methyl group at 3.03 ppm, Cr3; methylene group at 3.93 ppm, Cr2), trimethylammonium compounds (TMA at 3.2 ppm, mostly from phosphocholine, glycerophosphocholine and carnitine), lipids (0.9–2.5 and 5.3 ppm) and a resonance at 3.4 ppm probably attributable to taurine. ^{1}H-MR spectra of human skeletal muscle have been shown to feature orientation-dependent spectral patterns due to dipolar coupling [9,10]. The cardiac spectra do not show large dipolar splittings, but the Cr2 peak has a similar broadening pattern as for the soleus muscle in the calf (when oriented parallel to B_0). This is not unexpected, because the cardiac muscle fibers in the observed ROI are also not oriented parallel to the magnetic field and are probably also not homogeneously oriented within the whole ROI.

In contrast to skeletal muscle, the lipid resonances are not obviously separated into two components by susceptibility effects [11] (at least in the ROI studied). This makes it difficult to distinguish pericardial from intra-myocardial contributions to the lipid peaks.

4. Conclusions

Combined respiratory and cardiac triggering improves the localization accuracy and spectral quality in cardiac ^{1}H-MRS dramatically leading to substantially increased spectral reproducibility. The best practical realization of double triggering turned out to be the use of the ECG amplitude when making use of the fact that it is modulated by respiration. In spite of the spectral quality achieved in most subjects, we still fail to record satisfactory spectra in a minority of subjects. The reasons for this are not understood at present but must be some particulars of either a given subject or the experimental setup. The cardiac ^{1}H-MR spectra contain quantifiable contributions from creatine, TMA, lipids, and probably taurine. It is possible that the spectral contributions of creatine are subject to dipolar coupling similar to the observations for skeletal muscle.

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