Molecular imaging through $^1$H MRS and MRSI in everyday routine:
Improvements in various clinical applications and parameter
optimization of spectroscopic imaging sequences

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Abstract

In the era of molecular imaging, in vivo $^1$H magnetic resonance spectroscopy (MRS) and spectroscopic imaging (MRSI) are impacting dramatically upon virtually all areas of clinical medicine. MRS and MRSI should be able to identify key biochemical changes, much before the tumour becomes detectable by other functional imaging methods that mainly rely upon single markers that are not entirely sensitive or specific for malignant activity. Combined with other imaging techniques a rapidly advancing modality like MRI offer the ability to estimate the presence of metabolites yields much information regarding tissue. Molecular imaging through magnetic resonance could be potentially suited for screening and repeated monitoring since it entails no exposure to ionizing radiation. Incorporation of these tools in clinical practice is, however, limited due to the considerable amount of user intervention. In this work, various acquisition parameters and their effects in spectrum quality are investigated. In order to assess the quality of various spectroscopic techniques (2D and multi-slice MRSI, multiple echo SI), a series of experiments were conducted using a standard solution. The application of water and fat suppression techniques and their compatibility with other parameters were also investigated. The stability of the equipment, the appearance of errors and artifacts and the reproducibility of the results were also examined to obtain useful conclusions for the interaction of acquisition parameters. All the data were processed with specialized computer software (jMRUI 2.2) to analyze various aspects of the measurements and quantify various parameters such as signal-to-noise ratio (SNR), full-width at half-maximum (FWHM), peak height and j-modulation. The experience acquired from the conducted experiments was successfully applied in acquisition parameter optimization and improvement of clinical applications (two dimensional (2D) MRSI of prostate, brain and muscle MRS) by significantly improving the spectrum quality, SNR (up to 75%), spatial resolution in 2D MRSI, water and fat suppression and in some cases reducing exam times (up to 60%).

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1. Introduction

Magnetic resonance spectroscopy (MRS) and MR spectroscopic imaging (MRSI) are gaining acceptance as tools in the evaluation of various pathologies, benign and malignant. Thus far, MRS and MRSI-related studies have focused on the clinical trial of typical acquisition protocols on certain pathologies of various anatomical areas.

MRSI has been successfully applied to the diagnosis, spatial detection and staging of cancer in the peripheral zone of the prostate by detecting the levels of choline, citrate and polyamines [1]. MRSI has shown high sensitivity and specificity for detecting various pathologies of the prostate. MRS and MRSI have also been applied for the biochemical analysis of the brain and for the accurate
diagnosis of various benign, malignant, psychological and cognitive disorders. By detecting the levels of N-acetyl-aspartate (NAA), choline, creatine, myoinositol and glutamine it is possible in a non-invasive way to evaluate the condition of the examined tissue. MRS of the myoskeletal muscles has been proven valuable for the analysis of these tissues and the evaluation of various pathologies, by detecting the levels of intramyocellular (IMCL) and extramyocellular lipids (EMCL), choline and trimethylammonium (TMA). The aim of the present study was to evaluate the effects of acquisition parameters on the spectra and chemical shift imaging (CSI) images, in order to improve the clinical application of these techniques in every day routine. Also the limitations of the hardware for phantom measurements and clinical applications were assessed in order not to produce artifacts due to insufficient hardware capabilities.

2. Materials and methods

From October 2004 to September 2005 35 phantom measurements were conducted. Also 20 volunteers and 60 patients underwent combined MR imaging, MRS and MRSI for the evaluation of these techniques in prostate, brain and myoskeletal studies. MR imaging, MRS and MRSI studies were performed with a 1.5-T Intera NT MR imaging unit (Philips Medical Systems, Best, The Netherlands). Phantom measurements and examinations were conducted by using the head coil, the endocavitary coil and the 11 cm radius surface coil.

The acquisition parameters were evaluated and adjusted in order to gain high signal-to-noise ratio (SNR), reduce examination time and minimize the number of unsuccessful examinations. From the acquired T2-weighted images, a single voxel volume or a two-dimensional (2D) spectroscopic volume was selected with use of PRESS sequence to encompass the area of interest of the phantom or the tissue. The echo delay of the PRESS sequence was optimized for the quantitative detection of certain metabolites, ranging from 30 to 280 ms depending on the application. Water and lipid suppression was applied to assess the effectiveness of the available techniques and the compatibility with various examination protocols. Field of view (FOV) was ranging from 120 to 200 mm, with optimal results at 160 mm. Spectroscopic imaging data sets were acquired with a nominal spatial resolution of 0.3–0.6 cm$^3$.

The phantom is a sphere of 10 cm diameter containing: 5 ml 98% acetate, 10 ml 80% ethanol, 8 ml 98% phosphoric acid, 1 ml 1% arquad solution and 120 mg/ml CuSO$_4$ (total content 524 ml) [3]. Phantom studies were performed with 1200–2000 ms TR, 120 ms TE for the optimal analysis of the synthesis of the phantom; spectral bandwidth was 1200 Hz, data sampling was performed for 1024 data points and a maximum spatial resolution of 20 $\times$ 20 voxels with one signal acquired per phase encoding step.

Prostate studies were performed by using the endorectal and the surface coil, with 1000 ms TR and 120 ms TE to acquire spectra and CSI images to distinguish the peaks of citrate, choline and creatine and detect the spatial extension of the pathology. Spectral bandwidth was 1300 Hz, data sampling was performed for 1024 points and spatial resolution of 8 $\times$ 8–16 $\times$ 16 voxels (depending on the size of the tissue). Water suppression was performed with the WS-TE technique [3]. Fat suppression was not performed due to the demand of the hardware for higher TR (1850 ms) when combined with water suppression.

![Fig. 1. Phantom study TR = 1000 ms, TE = 120 ms, spectral resolution 20 $\times$ 20 voxels. High SNR for all peaks (150–320). Scan time: 11 min.](image-url)
techniques. Periprostatic areas containing fat, observed by the MR imaging were not included in the volume of interest in order not to affect the quality of the resulted spectrum [1].

Brain studies were performed by using the head coil. The examinations were performed with 2000 ms TR and 40, 120 and 280 ms TE depending on the application [4]. Water suppression was performed by applying either the WS-TE technique or selective excitation. Fat suppression was not performed. The voxel size for MRS and the size of the 2D grid for MRSI were variable due to the different requirements of the examinations [5]. The spectral bandwidth was 1200 Hz and data sampling was performed for 1024 points.

MRS of the myoskeletal tissues was performed by using the surface coil. The examinations were performed with 2000 ms TR and 30 or 120 ms TE for the discrimination of the peaks of creatine, TMA, IMCL and EMCL [6]. Water suppression was performed by applying the WS-TE technique or selective excitation. Fat suppression was not performed because of the diagnostic significance of the lipid signals. Spectral bandwidth was 1200 Hz and data sampling was performed for 1024 points.

Data processing was performed by using jMRUI 2.2. The procedure included 2–7 Hz apodization, phase and baseline correction, peak fitting and zero filling (1024 points for MRSI and 2048 points for MRS). CSI images were overlaid on the corresponding T2-weighted images. In order to measure the peak SNR the standard deviation of the signal intensity in a region of the spectrum containing only noise (12–15 ppm) was measured. Peak areas were normalized with respect to the noise standard deviation to yield the SNR for the assessment of the quality characteristics of the

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Fig. 2. Prostate 2D MRSI examination of 22-year old volunteer. TR = 1000 ms, TE = 120 ms, spectral resolution 20 x 20 voxels. High SNR for all peaks (3–7.4). Scan time: 18 min.

Fig. 3. Brain MRS examination of patient with grade III astrocytoma. TR = 2000 ms, TE = 40 ms, VOI size 2 cm³. High SNR for choline peak (17.4). Scanning time: 3 min.
3. Results and discussion

Phantom studies were performed to evaluate the interaction of various parameters, the effectiveness of the suppression techniques, the effects of bad protocol planning and the function of 3D and rapid CSI techniques (Figs. 1 and 2).

It was observed that in 2DSI grid, the SNR decreases with increasing distance of the phantom from the selected coil. The SNR for all peaks ranged from 120 to 340 and the scanning time was ranging from 4 to 14 min for 2DSI and 2–5 min for MRS.

Prostate studies were performed mainly for the diagnosis of malignant lesions. The peaks of polyamines were detected only in volunteer studies. The SNR, when using the surface coil ranged from 4 to 8 and when using the endorectal from 5 to 12. Scanning time was reduced from 31 to 18 min by retaining the same SNR levels (in comparison with the manufacturer’s protocols).

Brain studies were performed mainly for the evaluation of malignancies and temporal lobe epilepsy. The peaks of myoinositol and glutamine were detected in most cases. The SNR for the MRS studies ranged from 9 to 20 for most peaks and for MRSI from 4 to 12. Scanning time was 4 min for MRS examinations and 17 min for 2DSI.

Also multiecho 2DSI (TSI) was performed. In this case, due to undersampling (256 points) and very long TR and TE (2800/280 ms) only NAA (SNR = 5.2), choline (4.8) and creatine (4.6) could be detected. The scanning time was 4 min and 23 s (Fig. 3).

Myoskeletal studies were performed only in volunteers. The SNR was found 50 for IMCL and EMCL and 18 for creatine and TMA. All characteristic peaks, known from the literature were detected [6]. The exam time was approximately 3 min.

Based on the collected data it was found that spectral resolution, spatial resolution, scanning time and SNR are interrelated. Examination planning should be done very carefully to obtain efficient spectral and spatial resolution without loses in SNR and very long scan times. Also protocols that combine several techniques for signal suppression and volume selection are not appropriate for clinical applications (low SNR, artifacts, very long TE and TR).

4. Conclusions

The findings of the present study demonstrate that with simple changes in the imaging protocols and better examination planning it is possible to improve the quality of the examinations and reduce significantly the scanning time without using specialized hardware, complicated processing methods or sophisticated software tools.

References