Measurement of human brain temperature changes during cooling

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Introduction

Therapeutic brain hypothermia is used with increasing frequency as a tool to mitigate neurologic injury [1]. It has been shown that moderate cooling of the brain after hypoxia-ischemia can reduce damage and improve functional outcome [2, 3]. Recently a new method for selective brain cooling was described and prototype device was tested on the pigs [4, 5]. Brain temperature decreasing in the range 1-3 ^oC was detected. Main purpose of this study was to verify the proposed cooling method on the human volunteers and to compare two MR methods for noninvasive monitoring of the relative brain temperature: spectroscopic imaging (MRSI) with high spatial and reduced spectral resolution [5] and conventional proton resonance frequency (PRF) shift technique [6].

Materials and Methods

Ten healthy subjects were measured. Selective brain cooling was performed through both nasal cavities using water cooled balloon catheters [4]. Cooling water (~20 ^oC) at a flow rate of 100 ml/min was intended to induce hypothermia (33 ^oC to 35 ^oC) in ca 15 – 20 minutes. Measurements were performed on a 1.5 T MR scanner (Philips). The MRSI sequence was based on a 2D rf spoiled gradient echo [7]. The spectral information was encoded by incrementing the echo time $TE_m = TE_1 + m\Delta TE$ (TE_1 = 6 ms) of the subsequent eight image records (m = 0, 1…7). Image matrix (256, 256), FOV = 260 mm and 128 phase encoding steps led to resolution in plane of 1x2 mm. The slice thickness was 5 mm and net measurement time 41 seconds (TR = 40 ms, 1 acquisition). Incrementing the echo time by ΔTE = 1.56 ms led to a spectral bandwidth 10 ppm. Spectral resolution was 1.25 ppm. Data processing was described elsewhere [5]. Relative brain temperature was computed from the positions of the water spectral lines in each pixel/voxel (Fig. 1a). Phase maps (Fig. 1b) used in PRF method were computed from the first image record (TE = 6 ms) of the MRSI sequence. Temperature changes were computed using brain water chemical shift coefficient -0.019 ppm/^oC [5]. The experiment began with four baseline records. Selective cooling was then started (t = 0), and temperature changes were monitored by MRSI sequence. Typically, 20 MRSI acquisitions were repeated with a period of 1.5 minutes after cooling began.

Results

Brain temperature changes were computed from the position of the water spectral lines (Fig. 1a) and from the phase shifts (Fig. 1b). Figure 1c shows comparison of the relative temperatures measured by high-spatial-resolution MRSI and PRF method in the voxel V2 (Fig. 1a, b). Figure 2a shows positions of the voxels V1 – V4 (10 x 10 pixels/voxels, VOI = 0.5 cm^3). Correlation between both methods depicts Fig. 1d. Figure 2b shows distribution of the temperature changes at the end of the cooling (t = 40 minutes). Time course of the relative brain temperatures in the voxels V1-V4 during cooling are shown in Fig, 2c-f, respectively. Temperatures were measured using MRSI method. Full line represents smoothing of the measured values by adjacent averaging (5 points). The brain cooling resulted in a temperature reduction at all sites (Fig. 2b). It should be noted that the relative temperatures are incorrect in the frontal lobe (Fig. 2b, white area) due to large magnetic susceptibility artefacts in this part of the brain.

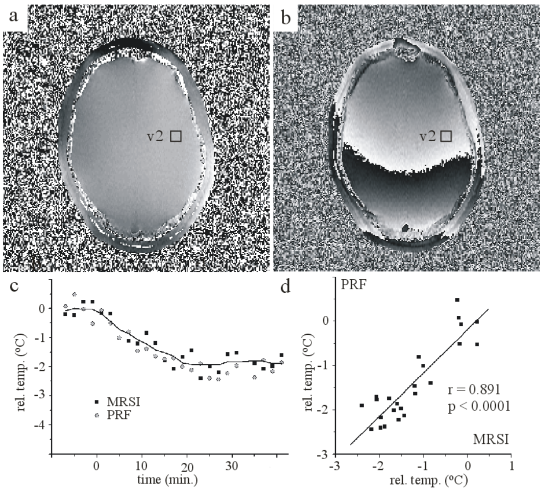

Fig. 1: Relative brain temperature was computed from the positions of the water spectral lines (a) and phases (b). (c) Time course of the relative temperature during cooling in the voxel v2. (d) Correlation of relative temperatures measured by MRSI and PRF techniques.

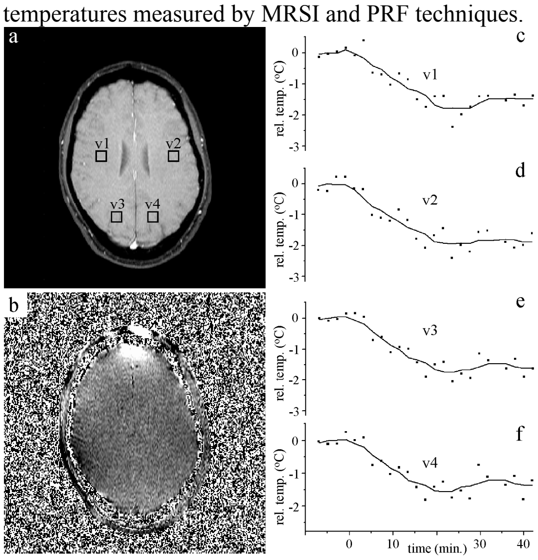

Fig. 2: MRSI results: (a) voxel positions (v1 - v4), (b) relative temperature map at the end of the cooling, (c-d) relative temperatures changes during cooling in the voxels v1-v4, respectively.

Discussion

Our results demonstrate that the proposed cooling method is capable to decrease human brain temperature about 1 to 3 ^oC in ca 15-20 minutes. Relative temperature measurements of four volunteers were successful. Sex experiments were excluded due to uncontrolled movement of the head. It was extremely difficult to achieve acceptable stability (< 1 mm) of the head during whole experiment (40 minutes) although fixation by foam pads. Very good agreement was found between relative temperatures measured by MRSI and PRF method. Main advantage of PRF method is its simplicity and short measurement time. Disadvantage is phase unwrapping that can complicate measurements in the areas of increased magnetic field inhomogeneities. MRSI technique avoids phase-unwrapping problem. Note, that the method does not require spectroscopic shimming. The ability of the MRSI to separate water and fat signals is advantageous for the measurement of the temperature in the tissues that contain fat (muscles, liver). Disadvantage is longer measurement time and more complicated data processing.

Conclusions

Ability of the proposed brain cooling method to induce moderate hypothermia was confirmed. Good agreement was found between relative temperatures measured by MRSI and PRF method. Both temperature mapping techniques can be used for monitoring the slow brain temperature changes during controlled hypothermia.

References

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