Quantitative analysis for optimizing the MRI temperature monitoring using Keyhole technique

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Introduction

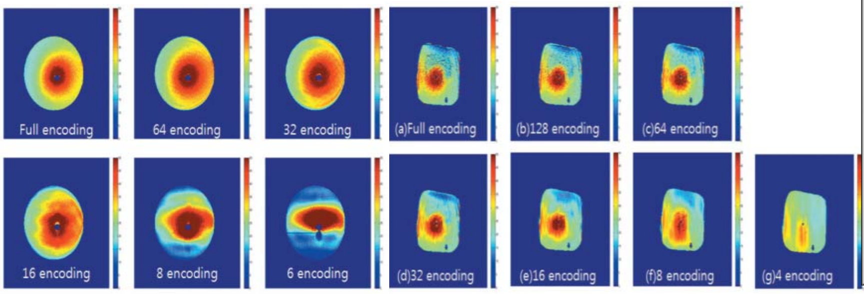
Magnetic resonance imaging (MRI) is usually implemented as a Fourier transform-based technique. As such, the imaging equation is in the form of a Fourier integral. For notational convenience, we define here the dynamic imaging problem as the acquisition of a sequence of Q images, denoted as $I_1(x), I_2(x), \ldots, I_Q(x)$, each of which is a snapshot of a time-varying image function $I(x,t)$. Conventionally, Q data sets in k-space, $d_1(k), d_2(k), \ldots, d_Q(k)$, are acquired independently such that $d_q(k) = \int_{-\infty}^{\infty} I_q(x)e^{-i2\pi kx}\,dx$. Assume that N sample data points (or encodings) are collected for each data set at $k = n\Delta k$, $-N/2 \le n < N/2$. The spatial resolution of $I_q(x)$ is limited to $1/(N\Delta k)$, whereas the temporal resolution is NT_R with T_R being the repetition time. Therefore, high spatial resolution requires a large N, which means poor temporal resolution. To overcome this problem, several data-sharing methods have been proposed for efficient dynamic imaging[1], an example of which is the Keyhole technique[2]. The Keyhole technique for MR temperature monitoring was proposed to improve the temporal resolution conducted on the swine's muscle tissue that was dependent on the combination of phase encoding portions taken from the central and peripheral parts of K-space. The values of Root Mean Square (RMS) error obtained from the keyhole and full phase encoded temperature images were compared. And through this quantitative analysis, we found an optimal phase encoding number of the central portion of the k-space using the proposed keyhole technique.

Materials and methods

The Proton Resonance Frequency (PRF) method[2-3] which combined with the GRE sequence was used to get the MR temperature images of agarose gel phantom and swine's muscle tissue using a clinical 1.5T MR scanner. A MR compatible coaxial slot antenna[3-4] was used to heat the phantom and tissue in the magnetic room for 5 minutes before scanning. The MR raw data was obtained by a sequential 10 minutes of acquisition during the cooling period. The imaging parameters were based on following sequences: TR/TE=300/2.6ms, FA=60°, NEX=1, matrix size=256×256, and scan time per image was 1 minute 19 seconds. The Keyhole images were reconstructed by taking the central part of K-space data with 128, 64, 32, 16, and 8 phase encoding lines while the remaining peripheral parts were taken from the 1st raw data[2]. The RMS errors were compared with the 256 full encoded self-reference temperature image. The paired t-test was used($p<0.05$ in all case) to optimize the proposed Keyhole technique.

Results

Figure 1 shows the temperature variation generated by changing the phase encoding number at the center part on the Keyhole temperature images at the local heated regions created by the antenna. When the number of phase encoding line decreases, the resolution of the resultant temperature image becomes poorer and blurred. Figure 2 displays the plot of RMS error of thermal distribution from the total Keyhole images. The RMS variations increase as the number of phase encoding line taken from the center part of each K-space in the Keyhole image decreases, especially the 8 phase encoded image which shows the maximum thermal error >5°C; whereas the 128 phase encoded image only shows the thermal error of <1°C. Table 1 depicts the P-values of the paired t-test at 8, 16, 32, 64 and 128 encoded Keyhole images. The images reconstructed <32 phase encoding line were not useful because the p-values of the 16 and 8 phase encoded images were <0.05 and <0.001 respectively.



(a) agarose gel phantom **(b)** swine's muscle tissue

Figure 1. The comparison of the phase encoding number at the center part of k-space for the keyhole MR temperature monitoring using (a) and (b)

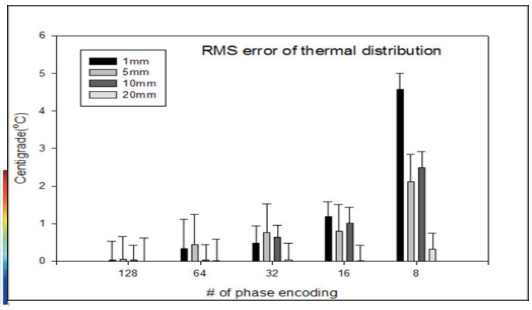


Figure 2. RMS error of thermal distribution

Table.1 Result of P-values from the paired t-test

Number of encoding	Distance from antenna tip(mm)	mean±SD(°C), n=9	P-value
128 encoding	1	72.57±1.62	0.955
	5	60.66±1.81	0.957
	10	43.40±1.02	0.951
	20	25.08±1.22	0.998
64 encoding	1	72.20±2.17	0.677
	5	61.15±2.63	0.669
	10	43.46±1.10	0.954
	20	25.08±0.81	0.989
32 encoding	1	72.05±1.05	0.326
	5	61.46±2.70	0.480
	10	42.80±0.82	0.149
	20	25.04±0.47	0.937
16 encoding	1	71.35±1.39	0.053
	5	61.50±2.55	0.443
	10	42.41±1.02	0.044*
	20	25.09±0.39	0.980
8 encoding	1	67.96±1.53	<0.01*
	5	58.59±2.73	0.067
	10	40.93±1.07	<0.01*
	20	24.75±0.42	0.479

Discussions and Conclusions

This study concludes the Keyhole technique increases the time resolution whilst increases the thermal error too. Therefore we could select the optimal number of phase encoding by considering these conditions. According to the quantitative analysis in this study, authors concluded that the 32 phase encoding number applied for keyhole is acceptable when $P<0.05$. In future, it is expected to implement the MR real time thermal imaging using Keyhole method which is able to reduce the scan time with minimal thermal errors.

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