Reducing T_2 blurring in Fast Spin Echo Sequences Using the Point Spread Function

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Introduction: Fast (or Turbo) spin echo (FSE, TSE) pulse sequences are widely used in clinical imaging but they suffer from blurring when high spatial frequencies are attenuated by T_2-effects. This blurring is especially pronounced at high field when T_2 is shorter. We have developed a method to reduce blurring effects using an appropriate point spread function (PSF) measured by a modified TSE sequence but without deconvolution. The method restores image sharpness at reasonable additional scan times.

Theory: In TSE blurring occurs along the phase encoding y-direction, so only a 1-D PSF is required. Fig.1 shows the modified TSE sequence containing extra step gradients used to measure the PSF. We then use the resulting PSF $P_2(y',y)$ to reduce blurring through convolution using eq. (4).

A. Blurred image in TSE:

The signal in TSE can be written as:

$$S(k_y)=\int \rho(y)e^{i2\pi k_y y}e^{-T(k_y)/T_2(y)}dy \qquad (1)$$

Performing an inverse FFT, gives the blurred image $\rho'(y')$

$$\rho'(y') = \int \rho(y)\times P_1(y,y')dy \qquad (2)$$

where $P_1(y,y')$ is the PSF which transforms $\rho(y)$ to $\rho'(y')$, and

$$P_1(y,y')=\int e^{i2\pi k_y (y-y')}e^{-T(k_y)/T_2(y)}dk_y \qquad (3)$$

B. Correcting for blurring:

By finding a corresponding PSF $P_2(y',y)$ which transforms $\rho'(y')$) to $\rho(y)$, we can use the following to reduce blurring.

$$\rho(y) = \int \rho'(y')\times P_2(y',y)dy' \qquad (4)$$

C. Determining the PSF:

To determine the PSF, we apply extra step gradients along the phase encoding direction, so the measured signal becomes:

$$S_1(k_y,k_1)=\int \rho(y)e^{i2\pi k_y y}e^{-T(k_y)/T_2(y)}e^{i2\pi k_1 y}dy \qquad (5)$$

Performing Inverse FFT of $S_1(k_y,k_1)$ gives

$$\rho_1(y,y') = \rho(y)\times P_1(y,y') \qquad (6)$$

As shown in Fig.2, $P_2(y',y)$ can be written as

$$P_2(y',y) = \frac{\rho_1(y,y')}{\int \rho_1(y,y')dy} \qquad (7)$$

The meaning of $\rho_1(y,y')$ can be interpreted by considering that every pixel of $\rho(y)$ is spread into a row of the $\rho_1(y,y')$ matrix, and the sum of each row is equal to $\rho(y)$, while the sum of every column of the matrix $\rho_1(y,y')$ is equal to $\rho'(y')$. Thus

$$\rho'(y') = \int \rho_1(y,y')\,dy \qquad (8)$$

$P_2(y',y)$ is the fraction of the value in $\rho'(y')$ needed to transform back to $\rho(y)$, as expressed in eq. (7). Using eq. (7) and (4), we can reduce the T_2 blurring in TSE.

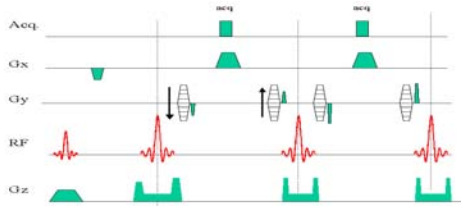

Fig. 1 Modified TSE to measure the PSF

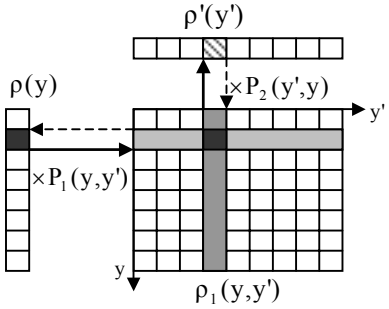

Fig. 2 The relationships among $\rho(y)$, $\rho'(y')$, $\rho_1(y,y')$, and PSF $P_1(y,y')$, $P_2(y',y)$. Each single pixel in $\rho(y)$ is spread to a row in $\rho_1(y,y')$, and the sum of each column becomes $\rho'(y')$; Each single pixel in $\rho'(y')$ is spread to a column in $\rho_1(y,y')$, and the sum of each row becomes $\rho(y)$.

Methods: To verify our method, the PSF method was implemented on a Philips Achieva 3T system. Images were acquired of an oil phantom, a Philips resolution phantom and a human head. The parameters were as following: Field of view FOV = 24 cm, slice thickness 4 mm, TE = 30 msec, and TR = 2500 msec for TSE, and 500 for SE, ETL = 64, echo space = 30 msec. 64 TSE reference scans were acquired with different step gradients. For comparison, a SE scan image was also acquired.

Results: Fig. 3 shows images of (a) the oil phantom (b) resolution phantom and (c) a human head. The images are SE (left) TSE (middle) and deblurred TSE image (right).

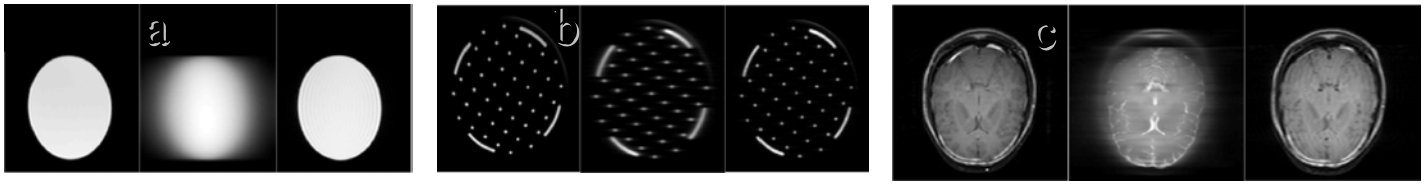

Fig.3 Images for oil phantom (a), resolution phantom (b) human head (c), left are from SE, middle are from TSE and right are deblurred TSE

Discussion: By measuring the PSF, we can reduce T_2 blurring in TSE by appropriate correction. The additional time needed to acquire the reference scan can be reduced if we use a smaller field of view for PSF which is wide enough to cover the maximum width of the PSF. By using the PSF from the measured image space to the original image space, deconvolution, which is very sensitive to noise, is avoided, and thus better results are achieved.