BLADE-VAT for Geometric Distortion Correction

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Introduction

MRI images suffer from geometric distortion from field inhomogeneity, induced by chemical shift, susceptibility, or implant metallic devices. The view angle tilting (VAT) [1] corrects for in-plane distortion by adding a gradient on the slice-select axis during readout, but it may suffer serious image blurring. Methods, which employ high-bandwidth readout [2], have been proposed to alleviate such blurring, while SNR reduction limits their applications. In this abstract, we present a novel method, which works without the high-bandwidth readouts and more importantly, can provide efficient reduction of the blurring in the VAT by low resolution acquisition in RO direction.

Methods

The k-space data is collected by N_B rotating blades (see Fig1, N_B=5), which is similar with the conventional Propeller acquisition [3], but each blade consists of N_{PE} parallel linear trajectories (N_{PE} is the number of phase encoding (PE) lines of the final reconstructed image). Each of the N_{PE} lines consists of L points of the lowest frequency samples in the readout (RO) direction of the k-space (total N_{RO} points to reach full resolution). This acquisition scheme provides low resolution in the RO direction, but high resolution in the PE direction in each blade. These blades can be acquired by SE or TSE manner. The blades are successively rotated in k-space by an incremental angle π / N_B (see Fig. 1). In each phase encoding line, VAT gradients are added for distortion correction.

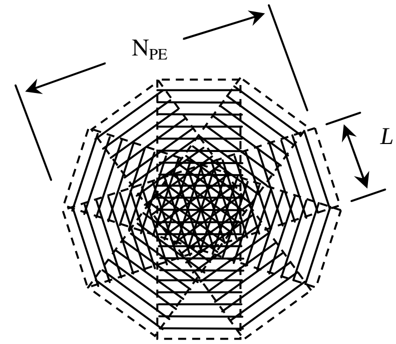

Fig 1. illustration of k-space coverage for the BLADE-VAT acquisition, with low resolution in the readout direction (L points of total N_{RO}).

For VAT imaging, a rectangular voxel shape is distorted into a rhombic shape in the RO direction (see Fig. 2), but no distortion in the PE direction. Using value of the shaded triangular area (seen in Fig.2b) divided by the total voxel area, the blurring degree can be quantified, denoted as *BR***.** For the conventional VAT correction,

$$BR_{VAT} \approx (\Delta s \cdot \tan\theta)/(2 \cdot \Delta x) \qquad (1)$$

For BLADE-VAT, because all the blades provide only low resolution components in each RO direction (see Fig. 2c), and no blurring exists in each PE direction, then *BR* for each blade can be estimated as:

$$BR_b \approx (\Delta s \cdot \tan\theta)/(2 \cdot r \cdot \Delta x) \qquad (2)$$

r is the ratio of desired high resolution in the final reconstructed image to low RO resolution obtained in each blade.

Additionally, for BLADE-VAT, the blurring is spread into all directions in the final reconstructed image instead of only RO direction for the Cartesian acquisition, which comes from the averaging effect of all blades. So the final blurring degree in an arbitrary direction for BLADE-VAT should be about 1/2 of that in the RO direction of each blade, the final *BR* should be

$$BR_{BV} \approx (\Delta s \cdot \tan\theta)/(2 \cdot 2 \cdot r \cdot \Delta x) \qquad (3)$$

Then, for BLADE-VAT, the blurring degree is only $1/(2 \cdot r)$ of the conventional VAT correction.

A TSE sequence was modified to implement VAT technique and the new technique BLADE-VAT. In Fig. 3a~d, two stainless steel boltes were attached to a large phantom with deliberate small structures. Images are acquired with three sequences: TSE, TSE with VAT, TSE with BLADE-VAT, using same scanning parameters: same readout bandwidth (201 Hz/ Pixel), TR/TE=500ms/10ms, readout direction: left-right for TSE and TSE with VAT. In Fig. 3e~f, a volunteer with metallic false teeth was scanned using the same parameters as in Fig.3 a~d.

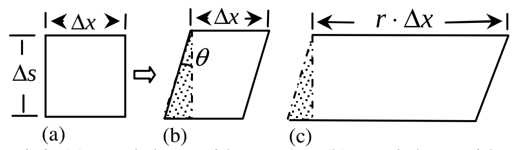

Fig2. (a) voxel shape without VAT; (b) voxel shape with VAT; (c) low resolution voxel in each blade for BLADE-VAT; Δs is excitated slice thickness, $\Delta x = FOV_{RO} / N_{RO}$ is the full readout resolution, θ is the tilted view angle; r is ratio of N_{RO}/ L

Results

The TSE with VAT has recovered the image structure, but introduced serious blurring. BLADE-VAT (r =8, total measurement time=5minutes) has also removed the in-plane geometric distortion, while obtaining a clear delineation of small structure and maintaining good signal-to-noise ratio: $SNR_{BLADE\text{-}VAT} \approx 64$ ($SNR_{TSE} \approx 58$).

Discussion

The increased acquisition time is a challenging problem, however, by integrating partial Fourier imaging or parallel imaging into TSE based acquisition, the total measurement time can be decreased into a tolerable extent, usually 2 to 5 minutes for T1-weighted images.

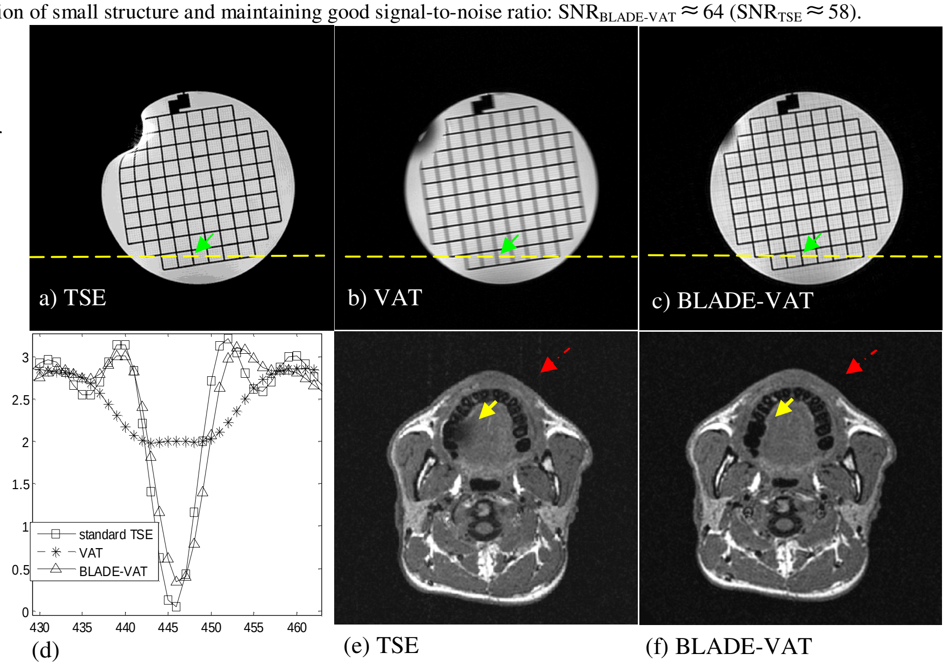

Fig3. Images acquired using (a) standard TSE, (b) TSE with VAT, (c) TSE with BLADE-VAT, and (d) a segment of the intensity profile along the dashed lines. Note that the image blurring in BLADE-VAT has been dramatically reduced to a negligible degree (see green arrows), without any SNR loss compared to TSE; (e) image distortion due to metal false teeth in volunteer scanning, see the yellow arrows; (f) corrected image with BLADE-VAT acquisition, maintaining a good delineation of the small tissue, and additionally, immune to pulsating artifacts, see red arrows.

References

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