Diffusion Tensor Imaging using SENSE-single-shot EPI

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Introduction

Anisotropy measures derived from diffusion tensor imaging (DTI) are excessively sensitive to measurement errors. Residual ghostings, for example, will hardly impair the diagnostic interpretation of conventional diffusion-weighted images whereas ghostings at the same level may be critical when quantitating diffusion anisotropy. So far, single-shot EPI (sshEPI) is the most frequent method for DTI because of its robustness against motion artifacts and its fast image acquisition capability. SshEPI, however, is prone to field inhomogeneities, chemical shift, and image blurring which all may distort anisotropy measurements. In this context, it has recently been shown that the increased k-space velocity - intrinsic to parallel imaging techniques such as SENSE (1) - can be used to strongly ameliorate image quality of diffusion-weighted images (2, 3). We therefore decided to investigate the feasibility of SENSE-sshEPI for DTI and to show its potential for artifact reduction and resolution enhancement.

Methods

Eight healthy volunteers as well as four patients suffering from multiple sclerosis were imaged on a conventional clinical 1.5-T unit (Philips Gyroscan ACS-NT; Gmax=21-mT/m, SRmax = 105-mT/m/s) with two distinct SENSE-sshEPI sequences (FOV=250-mm, thickness/gap= 6/0.6-mm, TE=92-ms, NEX=9). For all SENSE acquisitions, a dedicated six-element head array was used for signal reception. Diffusion-weighted SENSE-sshEPI scans were carried out along six directions, i.e., $(1\ 0\ 0)^T$, $(0\ 1\ 0)^T$, $(0\ 0\ 1)^T$, $1/\sqrt{2}(1\ 1\ 0)^T$, $1/\sqrt{2}(1\ 0\ 1)^T$, and $1/\sqrt{2}(0\ 1\ 1)^T$ and an additional scan without diffusion-weighting was obtained. The maximum b-value used was ~1045-s/mm² (Δ=47-ms, δ=30-ms). With a two-fold reduction, the acquisition matrices of the SENSE scans were either 42x128 or 42x256 and the EPI trains were further reduced by means of partial fourier imaging. Accordingly, a 3D gradient echo sequence (α/TR/TE= 15°/17.6-ms/4.6-ms) with interleaved data acquisition between the radio-frequency head array and the vendor's quadrature body resonator served for obtaining the reference scans. Subsequent coil sensitivity estimation was based on a variational approach (4). Ultimately, the eddy-current-induced image warping was removed by means of non-rigid registration based on constrained mutual information (5).

Results

Figures 1 and 2 clearly demonstrate the robustness of SENSE-sshEPI with respect to ghosting artifacts and image enhancement. Residual aliasing artifacts were not seen in any of the examinations. The corresponding fractional anisotropy (FA) maps allowed an excellent delineation of white matter tracts (Fig 2). Figure 2 also gives a side-to-side comparison between conventional SENSE-sshEPI (left column) and illustrates the further gain from SENSE-sshEPI with two-fold increased spatial resolution (right column). With both SENSE-sshEPI scans even the subcortical U-fibers could be traced using an associated fiber tracking algorithm. These U-fiber bundles usually have a lower FA than the major tracts and, thus, frequently are difficult to discern on common maps mainly for SNR reasons. MS lesion analysis in our patient examinations revealed an anticipated gradual loss of diffusion anisotropy in correlation with the degree of tissue destruction as well as a corresponding elevation of isotropic diffusivity.

Discussion

With this study we were able to demonstrate the feasibility of DTI in conjunction with SENSE. Preserving the advantages of a single-shot technique such as no need for phase navigation, we obtained images with markedly improved quality and with a spatial resolution which has not been possible with sshEPI so far. The high SNR of the given arrangement was advantegous for the fractional anisotropy (FA) maps so that even fine structures with low FA were discernible. The aliasing procedure of SENSE had no impact on the calculation of the diffusion tensor, except for a spatially variable SNR. In comparison to previous studies (2, 3), SENSE-recon strongly benefitted from the dedicated rf array. For practical purposes, improvement in image quality by SENSE-sshEPI should have a significant impact on the reliability and precision of derived diffusion tensor measures such as increasingly used in clinical studies of various CNS disorders.

References

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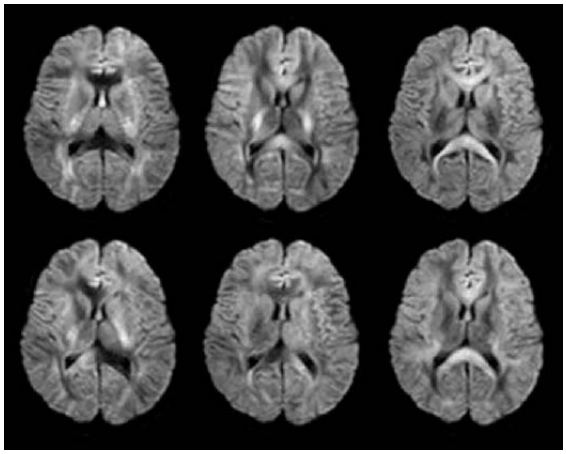

Figure 1 - Diffusion-weighted SENSE-sshEPI scans with diffusion-weighting along six different directions. No ghostings or residual aliasing is apparent. The images are free from any distortions around the frontal sinuses or the posterior fossa.

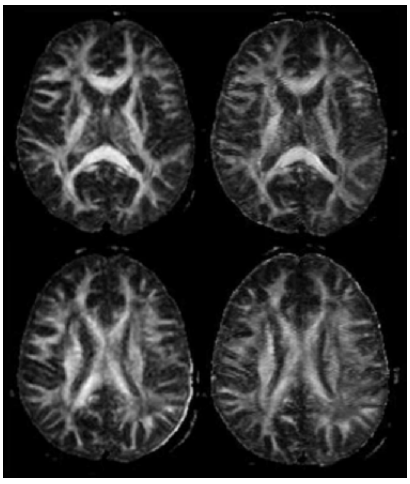

Figure 2 - Maps of the fractional diffusion anistropy from the same volunteer obtained either with SENSE-sshEPI (left column) or with high-resolution SENSE-sshEPI (right column). Even subcortical U-fibers are visible. Only subtle spatial changes in SNR are discernible owing to the SENSE recon.

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