Diffusion tensor imaging without geometric distortions using diffusion-weighted single-shot STEAM with partial Fourier acquisition

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Purpose:
Diffusion-weighted single-shot STEAM sequences (TSTEAM) provide an alternative solution to echo-planar imaging (EPI) for diffusion tensor imaging that is insensitive to susceptibility artefacts and geometric distortions [1]. A primary diffusion-weighted spin-echo replaces the first pulse of a single-shot STEAM sequence, where multiple differently phase-encoded stimulated echoes are read out by low flip angle pulses. In order to maintain a moderate signal decay and thereby a well-defined point spread function, the flip angles have to be rather low sacrificing signal to noise. Here, we adapted the use of single-shot STEAM with half Fourier phase-encoding [2] for diffusion-weighted single-shot STEAM with partial Fourier encoding. Typically, a reduction of the acquired Fourier lines to 5/8 was used in combination with a reconstruction by the projection onto convex subsets (POCS) method[3]. The gain of time was invested in an increased number of diffusion gradient directions yielding maps of the mean diffusion direction (MDD) of the human brain without geometric inaccuracies within acceptable measuring times.

Method:
Studies were performed at 2.9 T using a Siemens whole-body MRI system (Trio, Erlangen, Germany) with 40 mT/m gradients and a maximal slew rate of 200mT/m/s. Images were obtained with use of a transmit/receive or 8-channel phased-array headcoil. Written informed consent was obtained in all cases before the examination. While full Fourier (FF) acquisitions were based on 80 lines, partial Fourier (PF) studies employed 50 lines. In either case the spatial resolution was $2x2mm^2$ ($160x256mm^2$ FOV) with 4mm section thickness. Phase encoding was performed using centric reordering for FF and the central 20 lines for PF. The POCS algorithm for PF image reconstruction was added to the scanner, with a 5-fold iterated process providing sufficient phase conformity. PF phase-encoding allowed to increase the flip angle from 8.5° for FF to 11° for PF without affecting the point spread function. For diffusion tensor imaging 24 gradient directions were chosen corresponding to two icosaheders (e.g.[4]) at a b value of $1000s/mm^2$. Images without diffusion weighting were averaged 8 times.

Results and Discussion:
Figure 1 shows a comparison of FF and PF images using the same bandwidth (180Hz/pixel), but increased flip angles for PF, resulting in a slightly better SNR. With a repetition time of TR=7.25ms for the individual readout intervals of the single-shot STEAM sequence and an echo time of TE=50ms for the leading diffusion-weighted spin echo, the acquisition of 13 sections was achieved in 20min. Figure 2 shows selected MDD maps of the brain of a normal subject. It turns out, that the geometric congruence of STEAM-derived MDD maps with T1- or T2-weighted anatomical images represents a major technical advance. This achievement may indeed emerge as a clinical necessity in respective patient studies. This particularly applies to the use of anatomically defined start and target regions for fiber tracking.

References:
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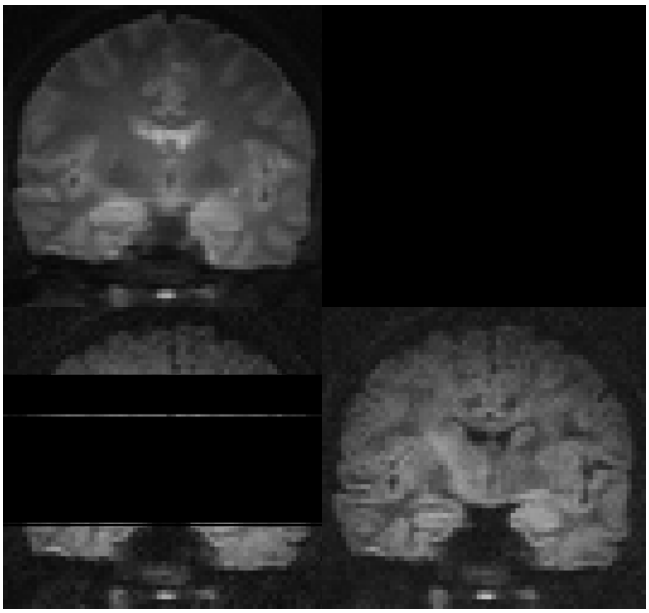

Figure 1 :Single-shot STEAM images with (left) full Fourier (FF) phase-encoding acquired in 660ms and (right) partial Fourier (PF) acquired in 442ms.
(Top) Without diffusion weighting, (bottom) $b=1000s/mm^2$.

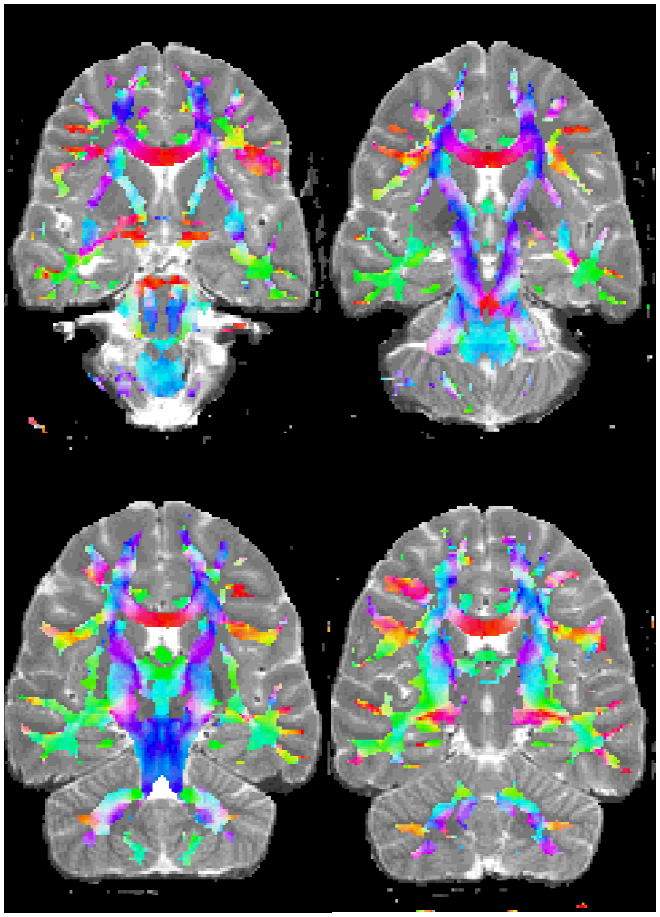

Figure 2: Selected MDD maps atop anatomical T2-weighted images of a normal volunteer at $2x2mm^2$ resolution and 4mm section thickness (45° orientation against AC-PC)