Diffusion Weighted turbo-STEAM ZOOM Imaging of the Lumbar Spine

P. Hiepe[1], K-H. Herrmann[1], C. Ros[1], and J. R. Reichenbach[1]
[1]Medical Physics Group, Department of Diagnostic and Interventional Radiology, Jena University Hospital, Jena, Germany

INTRODUCTION — Diffusion contrast in MRI is gaining increasing importance for a variety of clinical applications including spinal diseases, e.g., caused by lumbar intervertebral disk (IVD) degeneration [1]. So far, most clinical applications in the field of diffusion weighted imaging (DWI) have relied on echo-planar imaging (EPI) although DWI EPI is limited by susceptibility artifacts (geometric distortion, signal loss) in less homogenous regions of the human body. Stimulated echo acquisition mode (STEAM) MRI with robust turbo-FLASH readout is a fast imaging technique with subsecond measurement times based on recalling stored longitudinal magnetization by refocusing low flip angle RF pulses [2]. DW images are insensitive to off-resonance effects due to chemical shifts or magnetic susceptibility differences and consequently represent a robust alternative to EPI [3]. This robustness against geometric distortions is traded against SNR by using a less signal efficient turbo-FLASH readout acquisition technique. To achieve maximum efficiency of the turbo-STEAM sequences a reduced number of PE lines is beneficial [4]. An effective way to shorten the echo train is to utilize the ZOOM imaging technique that uses an inner-volume excitation, which limits the excited FoV in the PE direction to include only the region of interest (ROI). This can be used to measure various regions of the body with a narrow FoV, e.g. lumbar spine, without the occurrence of foldover or aliasing artifacts.

MATERIALS AND METHODS — The basic RF and magnetic field gradient pulse sequence for DW turbo-STEAM ZOOM MRI is shown in Fig. 1. The first module, a diffusion weighted spin-echo preparation, is played out at the beginning of each acquisition and consists of a volume selective 90° excitation and 180° RF refocusing pulse in readout direction as well as field gradients for the diffusion weighting applicable in three orthogonal directions. The second module, the turbo-STEAM MRI module, is applied after the formation of the spin-echo and starts with a slice selective 90° RF pulse to select a volume along PE direction and to store the magnetization in the longitudinal direction. Only those spins at the intersection of both volumes will contribute to the later STE. A series of α-pulses subsequently consumes the stored longitudinal magnetization and is used for the imaging of a slice within the selected volume while producing n-differently phase-encoded STE signals. Due to T_1-decay in TM period and hence signal attenuation over the echo train a centric reordering scheme of the PE gradient table is beneficial for image brightness and contrast.

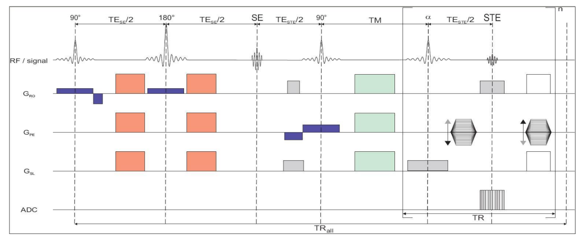

Fig. 1: DW turbo-STEAM ZOOM sequence: schematic pulse diagram with DW SE preparation period TE_{SE} and STEAM module (TE_{STE} + TM). DW gradients in orange, volume selective gradients in blue and crusher field gradients in green. The bracket refers to the repetitive readout interval for n-different PE lines refocused by α-pulses.

To determine ADC the DW gradients were applied in orthogonal gradient orientations (slice, readout and PE direction) to extract the diffusibility of water in IVDs. Three different diffusion weighting factors were used (b = 100, 150 and 250 sec/mm²). Initial studies were performed on a clinical 3T whole-body MR-scanner (Tim Trio, Siemens Healthcare, Erlangen, Germany) with an eight channel spine coil. DW turbo-STEAM ZOOM images were obtained in 366 msec with a 32 × 128 pixel matrix covering a rectangular FoV with 75 × 300 mm² and 6/8 PPF. Thus, the in-plane resolution was 2.34 × 2.34 mm² with a slice thickness of 7 mm. Timing was defined with TM = 17 msec, TR = 8.74 msec, TE_{STE} = 8.7 msec, TE_{SE} = 39.6 msec and TR_{all} = 2 sec. One healthy volunteer and one patient with former IVD degeneration were measured and the results were compared with results obtained from DW EPI sequences (2.2 × 2.2 × 3 mm, TE = 71 msec).

RESULTS — To estimate mean ADC of the DW STEAM data (images shown in Fig. 2) a ROI was placed centrally in each IVD on the ADC map. Analyzing the patient data measured with DW EPI (see Tab. 1) reduced ADC values were found in the degenerative IVDs L4-5 and L5-S1 in comparison to the normal IVDs L2-3 and L3-4. The ADC values of the healthy volunteer were larger for the lower (L4-5, L5-S1) compared to the upper IVD levels (L2-3, L3-4). ADC values determined with DW turbo-STEAM ZOOM MRI were found to be larger than the EPI ADC values, except the abnormal disks L4-5 and L5-S. Nevertheless, with both sequences decreased ADC values were obtained for the abnormal IVDs compared to the unaffected intervertebral disks (L2-3, L3-4).

Tab. 1: ADC values and standard deviations of the chosen ROIs in each lumbar intervertebral disk level.

IVD Level	Healthy Volunteer ADC [$\times10^{-3}$ mm²/s]		Patient ADC [$\times10^{-3}$ mm²/s]	
	ss-STEAM	EPI	ss-STEAM	EPI
L2-3	2.25 ± 0.23	1.90 ± 0.17	1.89 ± 0.34	1.82 ± 0.28
L3-4	2,30 ± 0.18	1.91 ± 0.25	2.09 ± 0.26	1.98 ± 0.20
L4-5	2.55 ± 0.15	2.07 ± 0.25	1.41 ± 0.42	1.77 ± 0.18
L5-S1	2.45 ± 0.11	2.02 ± 0.15	1.21 ± 0.35	1.57 ± 0.42

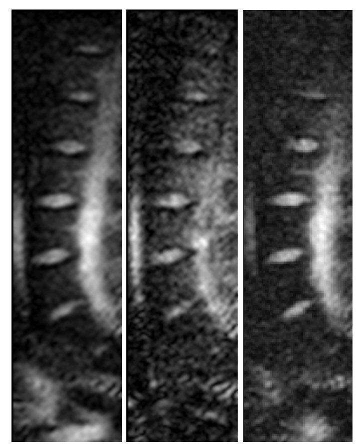

Fig. 2: Sagittal DW turbo-STEAM ZOOM images of the healthy volunteer (b = 0 s/mm² on the left side, b = 250 s/mm² in the middle and ADC map on the right side, including 9 averages in T_A = 18 sec).

DISCUSSION — An important feature of the STEAM MR images is the absence of susceptibility artifacts. In comparison with EPI, DW turbo-STEAM ZOOM MRI exhibits reduced SNR, but avoids regional signal losses and geometric distortions. Furthermore, no fat suppression is necessary. ZOOM imaging allows reduced FoVs and hence results in a decreased number of PE lines. Our case report indicates that the DW turbo-STEAM ZOOM MRI technique appears to be a good alternative to DWI EPI. For the assessment of the relationship between ADCs of IVDs and degeneration diseases further studies are necessary.

REFERENCES **[1]** Kealey S M et al. Radiology 2005 235:569-574; **[2]** Frahm J et al. Magn Reson 1985 65:130–135; **[3]** Nolte U G et al. Magn Reson Med 2000 44:731–736; **[4]** Finsterbusch J et al. Magn Reson Med 2002 47:611–615