An improved saturation scheme for measuring gagCEST in human knee at 7 T

Vladimir Mlynarik[1], Stefan Zbyn[1], Vladimir Juras[1], Pavol Szomolanyi[1], Martin Brix[1], Benjamin Schmitt[2], and Siegfried Trattnig[1]
[1]High Field MR Center, Medical University of Vienna, Vienna, Austria, [2]Siemens Ltd, Macquarie Park, Australia

Target audience
Musculoskeletal radiologists, MR physicists

Purpose
Glycosaminoglycan (GAG) molecules were shown to contain exchangeable OH protons that can be used as agents of chemical exchange saturation transfer (gagCEST).[1] However, practical application of this technique in human joints such as knee at 7 Tesla is complicated by technical limitations of MR scanners and by an inhomogeneous B_0 field in articular cartilage caused by complexity of the joint morphology. Furthermore, the amplitude of the saturation RF field is restricted by a SAR limit and the number of scans with different saturation offsets necessary for constructing Z-spectra is limited by a tolerable measurement time. To achieve equally efficient saturation of the OH protons in a broad range of resonance frequencies due to the inhomogeneous B_0 field, parameters of the saturation pulse train have to be adjusted with regard to the number and range of the frequency offsets. In this study, a new saturation scheme using a series of adiabatic full passage pulses with slightly varying pulse offset was proposed and tested for improving labeling efficiency in the gagCEST experiment in human knee cartilage.

Methods
Five volunteers were examined on a 7T MR System (Siemens, Erlangen, Germany) using a 28-channel knee array coil (Quality Electrodynamics LLC, Cleveland, OH). A prototype segmented 3D RF-spoiled gradient-echo (GRE) sequence (TE=3.46ms, TR=7.9ms, resolution=0.7×0.7×3mm^3) was combined with selective RF presaturation.[2] A series of five 99-ms Gaussian or ten 60-ms adiabatic full passage hs2 RF pulses followed by spoiling gradients with interpulse delays of 20ms was used. Thirteen scans with equidistant (140 Hz) offsets in the range of 1680 Hz around the water resonance and a scan without saturation were collected with each type of saturation pulses. The amplitude of the saturation pulses was adjusted to achieve about 80% of the SAR limit. Z-spectra were constructed from registered images on a pixel-by-pixel basis. Asymmetry of the Z-spectra was calculated from integrals over the offset range $\pm\partial$ = 0.6–1.8ppm relative to the minimum of each individual Z-spectrum.

Results
As estimated theoretically[3] and simulated by NMR-SCOPE[4], labeling efficiency of a saturation pulse train having mean B_1 typically about 0.5 μT was below 10%. With these pulse amplitudes, the frequency dependence of labeling efficiency is similar to the shape of the OH peak.[3] Comparison of measurements on volunteers with Gaussian and hs2 saturation pulses showed higher MTR_{asym} values obtained with hs2 pulses, probably thanks to reduced spillover (Fig. 1). However, unexpected variability of MTR_{asym} over different cartilage regions was observed with both saturation pulses. Since the $(\gamma/2\pi)B_0$ inhomogeneity in the knee cartilage was about 300 Hz (Fig. 2), saturation of the OH protons in different parts of cartilage was not equally efficient. The broader and flatter function of labelling efficiency covering the whole range of resonance frequencies of the OH protons was achieved by varying nominal (central) frequency of the hs2 pulses in a narrow range (± 60 Hz) around the offset frequency in the saturation pulse train (Fig. 3). The gagCEST measurement with the new saturation pulse scheme showed an increased (up to 13%) and more uniformly distributed MTR_{asym} compared to the standard pulse train (MTR_{asym} up to 8%, Fig. 4).

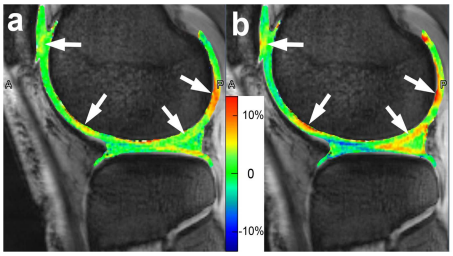

Fig. 1. MTR_{asym} maps of knee cartilage and menisci using five 99-ms Gaussian (**a**) or ten 60-ms hs2 (**b**) pulses. Note locally increased MTR_{asym} values in both maps (arrows)

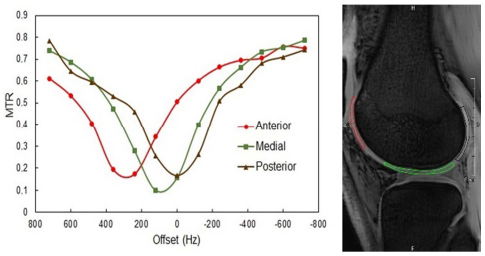

Fig. 2. Z-spectra for ROIs in anterior, medial and posterior femoral cartilage of a volunteer. The curve minima correspond to local resonance frequencies

Conclusions
Measurements with the constant offset of the saturation pulses showed inhomogeneously distributed MTR_{asym} in the knee cartilage of healthy volunteers. Compared with the standard saturation Gaussian pulse train, the proposed saturation scheme using variable offset of the hs2 pulses does not increase SAR and provides more uniform labeling efficiency in knee cartilage. Our measurements demonstrate improved MTR_{asym} maps with the new saturation pulse train in knee cartilage in vivo.

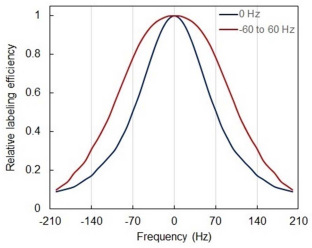

Fig. 3. Simulated labeling efficiency of an OH signal exchanging with water (τ_{ex}=1ms) using a train of pulses with a constant offset (blue) and with relative offsets of -60, -30, 30 and 60 Hz (red)

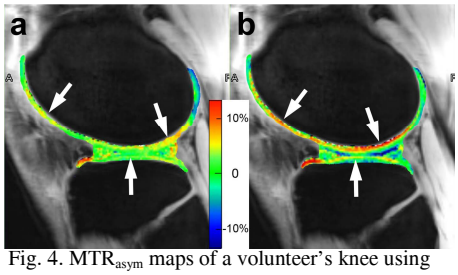

Fig. 4. MTR_{asym} maps of a volunteer's knee using standard Gaussian pulse train (**a**) and a train of hs2 pulses with variable (-60 to 60 Hz) offsets (**b**). Note the increased and more uniformly distributed values (arrows) in (**b**)

References
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