T1$_\rho$ imaging demonstrates inflammatory changes in disc endplates that were not visible in T1 or T2 weighted images

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Target Audience: Clinicians and researchers interested in the pathophysiology of spinal disc degeneration and endplate changes.

Introduction: The majority of chronic back pain is associated with degeneration of the intervertebral discs (IVD). In some patients scanned for low back pain, degenerative marrow changes are observed in the subchondral bones around the degenerating discs. These changes are classified using the scheme developed by Modic et al.[1] In type-1 changes, fissuring of disc endplates and vascularized fibrous tissues within the adjacent marrow were reported.[2] Discs with type-2 changes also show endplate disruptions as well as yellow (lipid) marrow replacement. Type-3 changes are usually associated with bone sclerosis. Although a direct association between Modic endplate changes and pain was not established to date, it is believed that the inflammatory mechanisms associated with those changes play a role in pain generation. Currently, Modic endplate changes are diagnosed based on the appearance of high or low intensity regions in T1 and T2 weighted MRI images. Although Modic classification using T1 and T2 weighted images is widely accepted, it is possible that those conventional techniques are not sufficiently sensitive to early changes. If endplate changes were detected earlier, alternative treatment techniques could be developed to manage pain more effectively. Moreover, only T1 and T2 weighted images are usually not sufficient to detect transition from type-1 to type-2. Novel imaging techniques are needed to detect early changes to type-1 or type-2. Recently, a few studies demonstrated changes in T1ρ relaxation rate in regions of inflammation in animal models of liver injury[3] and myositis in humans.[4] Since Modic changes induce inflammatory responses, we tested the efficacy of T1ρ imaging to investigate endplate degeneration.

Methods: This study was approved by the IRB and written consents were obtained from 39 adult participants who took part in this study (age: 20–57y; mean 36y). Image data were acquired using a 3T GE Discovery MR750 (Waukesha,WI USA) MRI system. All images were acquired with a CTL-spine coil, FOV=310mm and 16-sagittal slices with 3mm thickness. Conventional T2 weighted (T2W) and T1weighted (T1W) MRI were acquired using FSE sequence with 1mm in-plane resolution for Modic classification. T1ρ images were acquired using 3D MAPSS pulse sequence[5] with four spin-lock times (TSL) values = [0 20 40 60]ms, spin-lock amplitude=400Hz, and TR/TE=6.5/1.6 ms. Pixel-by-pixel T1ρ values were calculated based on mono-exponential fitting: $S(TSL)=S_0*exp(-TSL/ T1\rho)$.

Two expert radiologists reviewed T1W and T2W images and recorded endplate changes. Then, those reports were compared with T1ρ maps to observe changes in T1ρ values in regions identified by radiologists. Once endplate changes in T1ρ maps were validated by radiologist-confirmed regions, we also sought high T1ρ regions that were not detectable in T2W or T1W images. Those were marked as potential *early endplate degeneration* regions.

Results: Based on the radiologists' evaluation from T1W and T2W images, seven subjects had type-1 endplate changes at various lumbar levels; four subjects had type-2 changes and one subject had type-1 at L5 and type-2 at L3. Fig.1a-d shows a typical data from one subject (53 years old, female) who had chronic low back pain (Oswestry disability index=48). Fig.1 (a) and (c) show slices 6 and 9 from the T2W images and (b) and (d) show T1ρ maps fused onto T2W images. The T1ρ maps were thresholded at T1ρ=85 to highlight high T1ρ regions in vertebral body endplates (see colorbar). The radiologists have noted type-1 endplate changes at L2 and L3 vertebrae, which are also visible in both T2W images and T1ρ color maps (blue arrows). However, there were also prominent changes in inferior section of the L4, which were not visible in T2W or T1W images but highlighted in T1ρ color maps (green arrows). Additionally, in (c) and (d), the T2W images did not show the extent of Modic changes at L3 in slice 9, but significant increase in T1ρ was extending into that slice (orange arrows). In our cohort, endplate changes were typically of type-1 in the chronic low back pain patients. In those patients, T1ρ values were typically higher than 90ms and went up to 250ms in some patients with type-1 changes. The mean T1ρ was around 160ms for type-1 changes. On the other hand, type-2 changes were noted in four control subjects (with no history of chronic low back pain). In those type-2 changes, the T1ρ maps were generally unremarkable.
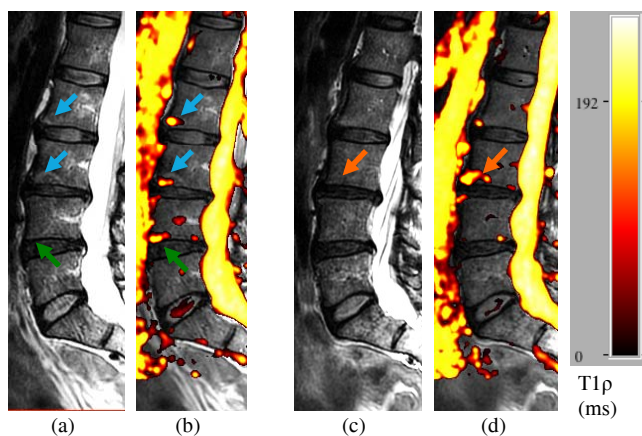

Fig.1. (a) and (c) are T2W image slices 6 and 9, respectively. (b) and (d) are the same slices with T1ρ maps overlaid in color. T1ρ color maps are thresholded at 85 to highlight high T1ρ regions.

Discussions and conclusions: Type-1 Modic endplate changes are usually thought to correspond to the inflammatory stage of degenerative disc disease and indicate an ongoing active degenerative process in the vertebrae; whereas type-2 changes represent conversion to fatty marrow. Type-2 changes are generally considered as a more stable and chronic process. Type-1 inflammatory changes usually involve the accumulation of collagen, proteoglycans and other macromolecules within the extracellular matrix. Accumulation of such macromolecules affects T1ρ relaxation rates, which has been reported in numerous publications. Results presented in Fig.1 demonstrate that T1ρ might be enhancing in regions where such inflammatory changes take place, but they were not visible in T1W or T1W images. Therefore, T1ρ mapping could provide valuable information about early inflammatory changes and their spatial extent in vertebral body endplates, which might be missed if conventional T1 and T2 weighted images were used. To the best of our knowledge, our findings are the first demonstration of the potential of T1ρ mapping to investigate endplate degeneration.

References: 1) Modic MT, *et al*. Radiology (1988);166:193–99; 2) Modic and Ross, (2007) 245:43-61; 3) Zhao *et al*. Eur Radiol (2012) 22:1709–1716 ; 4) Virta *et al*. (1998) Mag. Res. Img., 4:385–391; 5) Li X, *et al*. (2008) Magn Reson Med. 59:298-307.