In vivo MRI of rabbit intervertebral disc degeneration at 9.4 T: MR parameters quantification allows identification of degenerative discs

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INTRODUCTION

Intervertebral disc (IVD) degeneration is a complex process characterized by biochemical and structural changes in both nucleus pulposus (NP) and annulus fibrosus (AF). To study these mechanisms, we follow up the in vivo IVD degeneration by MRI on a rabbit animal model of human lumbar diseases using a homemade half-birdcage coil and a 9.4 T imaging spectrometer. MR images with several contrasts and quantitative parameters were acquired, and these data were statistically analyzed. To our knowledge, this is the first in vivo study of IVD degeneration on rabbit at high magnetic field.

MATERIAL AND METHODS

Animals and Surgical Technique. Female New Zealand White rabbits (weighting 1.75 ± 0.45 Kg and 10 ± 2 weeks old) were used. The surgical intervention was performed under French legislation and guidelines for animal experimentation. The skin and the tissues on the left flank were incised. Three lumbar intervertebral discs were damaged by a puncture-aspiration.

Magnetic Resonance Imaging Acquisition. All MRI experiments were performed using an imaging spectrometer equipped with a 9.4 T horizontal shielded magnet dedicated to small animal (94/21 USR Bruker Biospec) and ParaVision 4.0 software (Bruker Biospin MRI, Wissembourg, France).

MRI exams were carried out using a half-birdcage coil [1], before and 2, 4, 8, 12 and 16 weeks after surgical injury, with a multi-slice RARE sequence. Sagittal images were acquired with several contrasts: ρ-weighted, T_2-weighted and T_1-weighted images. The following geometry parameters were used: FOV 6 cm x 6 cm, matrix 256^2, 15 slices with 1 mm interslice gap, slice thickness 1 mm, in-plane resolution 234 µm x 234 µm.

MR Quantitative Parameters Acquisition and Analysis. The disc height was measured at three points of the disc from the sagittal ρ-weighted images and the values were then averaged for each disc. The disc and NP areas were measured for each IVD from whole NP and whole disc ROIs. The same ROIs were used to measure the disc and NP signal level from the ρ-weighted images (central slice).

T_2 relaxation times were determined using a Multi-Slice Multi-Echo (MSME) sequence with a series of 16 echo-images. T_2 values, averaged on several ROIs, were calculated from the signal decay curves non linear fitting and the corresponding T_2 parametric maps were also generated from this fitting.

We acquired diffusion weighted images along 3 orthogonal directions and calculated the trace of the diffusion matrix (TrD) [2]. Diffusion weighted images were obtained using a Stejskal-Tanner-type pulsed gradient stimulated echo (STE) sequence with four diffusion weighting factor values (b = 10, 60, 150 and 400 s/mm²).

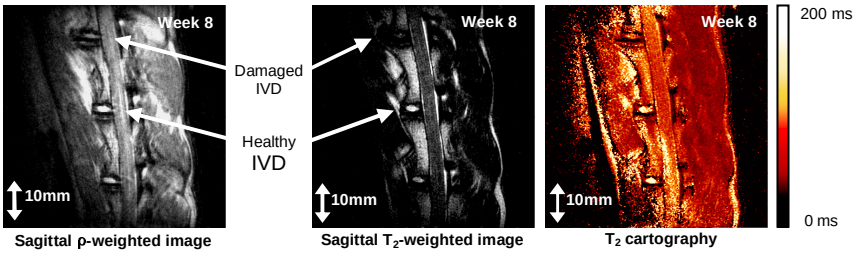
Statistical analyses of these data were performed using a Mann-Whitney test with a significance level of 5%, to determine the most discriminant parameters to differentiate healthy and degenerative IVD. Multi-parametric statistical methods were used to establish a classification of the disc degeneration phases from the MRI quantitative parameters.

RESULTS AND DISCUSSION

The analysis of the quantitative parameters gave high statistical significant differences ($p < 0.02$ for all the parameters) between degenerative and healthy discs. The results show that the disc TrD ($p=0.016$) is less discriminant than the other quantitative parameters. T_2 quantification in the NP and the whole disc, as well as the disc area and height give identical statistical results ($p=0.008$) between the different conditions of the IVDs.

It could be noted that the diffusion trace values measured on rabbit degenerative disc (mean value of 1.8×10^{-3} mm²/s) were in agreement with the values measured on human degenerative discs ($0.9 – 1.6 \times 10^{-3}$ mm²/s) by Kerttula et al. [3] and Antoniou et al. [4].

It was found that the multi-parametric statistical analysis of the several parameters allowed us to differentiate the different degeneration phase along the follow up of the in vivo disc degeneration.



CONCLUSION

Several contrasts and parameters quantification (ρ, T_1, T_2, TrD and T_2 quantification) were optimized and allowed to identify healthy and degenerative rabbit IVD, on high resolution in vivo images. These contrasts and parameters provided useful MRI tools to follow up in vivo the IVD degeneration processes (disc hydration loss, disc internal structure modification, disc height decrease and modification of disc and NP areas). We were able to establish a disc degeneration phase classification to characterize the disc degeneration processes chronology.

This work is a part of a larger project, aiming to study physiopathological mechanisms of IVD degeneration and regeneration, in vivo, and to estimate the efficiency of new disc restitution methods and new treatments in rabbit.

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