INTRODUCTION

Several quantitative MRI mapping techniques have been proposed for the assessment of the biochemical composition and structure of articular cartilage. This information may further be associated to the functional properties of cartilage, since the biomechanical properties of cartilage are determined by its structure and composition. T2 relaxation time mapping has been one of the most frequently used techniques for the biochemical evaluation of articular cartilage.

T2 relaxation time is the transverse relaxation time that is dependent on the interactions between spins and on tissue hydration (1). From a series of images with different T2-weighting the relaxation time may be estimated by fitting the data to the signal equation $S=S_0 \exp(-T2)$. The most frequent way of measuring such data in the clinical realm is by acquiring multiple echoes with different T2 weighting that follow a single excitation (multi-echo spin-echo sequence) (2). Currently, the major MRI vendors provide clinical tools for T2 mapping of cartilage.

T2 MAPPING IN EVALUATION OF CARTILAGE DEGENERATION

In articular cartilage, T2 relaxation time is affected by the properties of the collagen fibril network. Normal adult articular cartilage exhibits a laminar appearance in T2-weighted images or T2 relaxation time maps (3-6). This depth-wise pattern is attributed to the orientation-dependent residual dipolar coupling of spins oriented along collagen fibrils, also known as the magic angle effect (5,7). The T2 appearance has been connected to the histological zones of different preferential collagen orientation and organization of the collagen fibrils in articular cartilage: tangential zone with the fibrils running parallel to the articular surface, transitional zone with fibrils in relatively isotropic organization and deep radial zone with fibrils perpendicular to the cartilage-bone interface (8,9). T2 has also been associated with cartilage hydration (10).

Enzymatic treatment of cartilage revealed that T2 is particularly sensitive to the collagen fibril network integrity (11), although T2 elevation is also reported after proteoglycan depletion of cartilage (12). Various in vitro and in vivo studies have reported an elevation of T2 relaxation time with cartilage degeneration (13-15). However, it has also been reported to show shortened values in fibrous repair tissue as compared to healthy cartilage (16). T2 relaxation time has further been linked to the mechanical properties of cartilage (17).

In the clinical setting, typically the superficial zone is not identified due to the limited imaging resolution (18). Yet, T2 mapping has shown clinical feasibility and consequently has been applied in various patient populations. In subjects with osteoarthritis, T2 is not only elevated but also shows a more heterogeneous appearance (19). A recent two-year follow-up study revealed an elevation in T2 of load-bearing cartilage in subjects without radiographic joint changes but with known risks for OA development (20). Studies suggest that T2 may serve as a biomarker for early cartilage degeneration prior to advanced degeneration associated with cartilage loss.
T2 MAPPING IN EVALUATION OF CHONDRAL REPAIR

There are several reports on the usefulness of T2 mapping to evaluate chondral repair. Relaxation characteristics of repair tissue appear to depend both on the type and maturation of the lesion. In comparison to healthy cartilage, shorter T2 relaxation times were observed in histologically-confirmed fibrous repair in a minipig model of spontaneous repair after the generation of an osteochondral defect (16). In a goat model of microfracture Watanabe et al. reported prolonged T2 relaxation times without orientation dependence after rotation experiments in hyaline-like repairs (21). White et al. observed a lack of zonal variation of T2, typical to normal articular cartilage, in repair tissue after microfracture (22). These are examples of studies suggesting that T2 mapping may be a useful biomarker in the assessment of collagen anisotropy and in differentiating hyaline-like repair from fibrous repair tissue.

Several human studies have been conducted to assess chondral repair using T2 mapping. A study of T2 relaxation time for evaluation of autologous chondrocyte implantation (ACI) revealed that, at 1-year, the relaxation time for graft tissue is longer than that of a control hyaline cartilage and the graft tissue was absent from the typical zonal variation of T2 (23). Welsch et al. reported shortened T2 values with no zonal variation for repair tissue after microfracturing whereas for ACI with implantable matrices T2 was not reduced and there was an increase of T2 from deep to superficial zone (24). Trattnig et al. observed longer T2 values for ACI with implantable matrices as compared to reference tissue at 3-13 months. However, the T2 values approached those of control cartilage at 19-42 months (25). Another study by the same group found no zonal difference in T2 at 20 months after ACI, but a significant zonal stratification had appeared at 32 months after surgery (26). Oneto et al. reported that after microfracture initially elevated T2 values approached those of surrounding cartilage during the two-year follow-up time (27). The results suggest a difference in composition and structure between the repair tissues after various repair methods and reveal the feasibility of T2 mapping to evaluate cartilage repair.

CONCLUSIONS

T2 relaxation time mapping is an established method to evaluate articular cartilage and its repair, particularly the integrity of the collagen network. The technique can provide added value both to routine clinical evaluation as well as valuable biomarkers for clinical trials, and the technique is implementable on clinical systems with relative ease. For a comprehensive characterization of cartilage, however, T2 mapping should be combined with a proteoglycan-sensitive MRI technique.

REFERENCES

early cartilage changes after one
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