Biochemical MRI of human femoral cartilage in vivo: relationships with arthroscopic indentation stiffness and defect severity

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INTRODUCTION

Significant associations have been previously established between several biochemical MRI parameters and mechanical properties of articular cartilage in vitro [1-3]. As articular cartilage has mechanical function, it would be desirable to predict the mechanical characteristics of the tissue non-invasively. T2 relaxation time mapping is sensitive to the three-dimensional collagen network [4] whereas delayed Gadolinium Enhanced MRI of Cartilage (dGEMRIC) reflects the content and distribution of proteoglygans (PG) in cartilage [5]. The aim of the present study was to determine the usability of quantitative MRI methods to reveal early mechanical and visual cartilage alterations in vivo, as determined by arthroscopic indentation stiffness measurements and the ICRS cartilage defect classification system, respectively [6].

MATERIALS AND METHODS

Fifteen patients with clinically suspected cartilage changes and programmed arthroscopy were selected for the study. The institutional review board approval was obtained, and all participants gave their informed consent. Then, biochemical MRI was conducted prior to arthroscopy, followed by arthroscopic indentation measurements of cartilage stiffness. For biochemical MRI, a multi-slice multi-echo spin echo sequence (TR=1000, TE=10, 20, 30, 40, 50, 60, 70, 80 ms ETL=8) was used to determine the T2 relaxation time for knee cartilage. Consequently, a 0.2mM/kg (double dose) of Gd-DTPA(2-) (Magnevist, Schering, Berlin) was intravenously injected, followed by 10 minutes of joint loading exercise and total delay of 90 minutes prior to T1 mapping. A single-slice inversion recovery fast spin echo sequence (TR=1800, TE= 14.6, TI= 50, 100, 200, 400, 800, 1600 ms, ETL=6) was applied. The sagittal slice was positioned perpendicular to a line tangential to posterior femoral condyles in the axial scout view. One slice from both medial and lateral side was acquired for dGEMRIG series from the center of the condyle. T2 and dGEMRIC values for bulk, superficial and deep cartilage were determined at three ROIs for both condyles (Fig. 1). At arthroscopy, cartilage stiffness was measured at approximately same anatomical sites using an arthroscopic cartilage indention device (Artscan 200, Artscan Ltd, Helsinki, Finland) by instantaneously pressing the cartilage with a rod force of 10N and registering the indenter force [7]. The measurement was repeated 3-5 times and the mean value of three highest indenter forces was calculated. Additionally, cartilage at the measurement sites were graded according to the five-point ICRS cartilage classification system [6]. For statistical analyses, MRI parameters between different ICRS score groups were compared using the non-parametric Mann-Whitney test. Linear Pearson correlation coefficients between quantitative MRI parameters and cartilage stiffness were calculated.

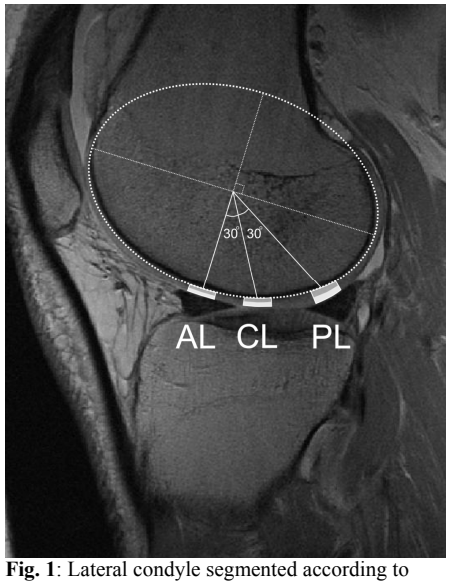

Fig. 1: Lateral condyle segmented according to cartilage stiffness measurements. (AL = antero-lateral, CL = central lateral, PL = posterolateral)

RESULTS

Cartilage stiffness was related to defect severity as measured by the ICRS classification system (Table 1). Bulk and superficial T2 values at different topographical locations increased along defect severity, however, the differences between groups were statistically insignificant. Similarly, dGEMRIC showed a trend for decreasing index values with increased severity for full-thickness and superficial ROIs ($p<0.05$). Significant linear correlations ($r\approx-0.6$) were observed between the T2 values and cartilage stiffness at the central and posterior medial condyle for bulk tissue, superficial T2 of the medial posterior condyle and deep T2 values at the central medial condyle (Table 2). T2 was not correlated with the stiffness measurements in the lateral compartment. dGEMRIC correlated only with the cartilage stiffness at the deep ROI of the medial anterior segment.

DISCUSSION

In this study, for the first time, biochemical MRI parameters have been related to cartilage defect severity and cartilage stiffness at arthroscopy. T2 and dGEMRIC showed a trend with the severity of lesions. T2 was negatively correlated with the cartilage stiffness at several ROIs of the medial compartment while dGEMRIC was negatively correlated, against the hypothesis, at one ROI of the medial compartment. Previously, dGEMRIC was positively related with cartilage stiffness of cartilage repair tissue in a limited number of subjects (N=4) with autologous chondrocyte transplantation [7].

The dynamic mechanical properties of articular cartilage, such as those measured during instantaneous arthroscopic indentation, are strongly controlled by the structure of the superficial collagen network. The equilibrium compressive stiffness is more closely attributed to the tissue PGs [8]. This was verified in the present study by the higher correlation of T2 with cartilage stiffness. The low correlation of biochemical MRI and tissue stiffness at the lateral condyle may relate to more homogenous data in that area; most of the cartilage lesions were situated at the medial condyle providing a wider range of variability in MRI and mechanical properties. Additionally, the dGEMRIC measurement was limited by the single-slice measurement at each condyle. Using anatomical landmarks, the MRI analyses and the very focal stiffness measurements do not match in site perfectly. Nonetheless, the trends observed between the quantitative MRI parameters, cartilage stiffness and severity of cartilage defects suggest that biochemical MRI measurements of articular cartilage may be related to the mechanical integrity of articular cartilage in vivo.

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Table 1: The mean values ± SD of the measured cartilage stiffness and the MRI parameters for pooled data. ICRS grades correspond to normal cartilage (grade 0), softened, fibrillated or superficially lacerated cartilage (grade 1), and cartilage with defects extending not deeper than 50% of the cartilage thickness (grade2).

ICRS grade	0 (N=65)	1 (N=28)	2 (N=9)
Stiffness	3.1 ± 1.0	2.9 ± 1.5	0.7 ± 1.0 [a b]
$T_{2\ bulk}$	39.5 ± 10.1	37.9 ± 9.9	44.9 ± 8.3
$T_{2\ surface}$	48.0 ± 12.0	46.2 ± 11.5	55.3 ± 12.2
$T_{2\ deep}$	31.0 ± 10.6	29.4 ± 9.7	34.0 ± 7.7
$T_{1\ bulk}$	500.6 ± 99.6	471.5 ± 75.6	449.2 ± 132.9
$T_{1\ surface}$	477.4 ± 97.4	450.1 ± 78.2	423.4 ± 147.6
$T_{1\ deep}$	531.1 ± 118.0	494.0 ± 81.9	471.4 ± 129.2

[a] sig. different compared to grade 0 (Mann - Whitney)
[b] sig. different compared to grade 1 (Mann - Whitney)

Table 2:Linear Correlation Coefficients between quantitative MRI and cartilage stiffness (AM = anteromedial, CM = central medial, PM = posteromedial)

	$T_{2\ bulk}$	$T_{2\ surf}$	$T_{2\ deep}$	$T_{1\ bulk}$	$T_{1\ surf}$	$T_{1\ deep}$
AL	0.17	0.09	-0.06	0.33	0.43	0.19
CL	0.28	0.44	0.08	0.01	0.05	0.06
PL	0.52	0.38	0.42	-0.12	-0.18	-0.04
AM	-0.25	-0.37	-0.15	-0.45	-0.16	-0.58*
CM	-0.57*	-0.41	-0.62*	0.15	0.16	0.14
PM	-0.56*	-0.62*	-0.41	0.32	0.49	0.21

* $p<0.05$