VARIATION OF LAMELLAR LAYER THICKNESS IN HUMAN MENISCI ON ULTRASHORT ECHO TIME (UTE) IMAGING: CORRELATION WITH INDENTATION STIFFNESS

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INTRODUCTION: Meniscus is a crucial structure that preserves articular cartilage integrity in the knee and contributes to normal knee function. The advent of ultrashort-echo time (UTE) MR imaging enables selectively imaging short T2 signal and provides high spatial resolution and contrast allowing identification of anatomic structures of the menisci contributing to a high signal-intensity appearance[1]. We have observed variations in thickness of the lamellar layers on meniscal femoral and tibial surfaces. Little information is currently available regarding the relationship between lamellar layer thickness and biomechanical properties in the human meniscus. The purpose of this study is to determine the relationship between lamellar layer thickness and indentation stiffness of human menisci.

METHODS: ***Samples.*** Five meniscal pieces (5mm-thick) were obtained from 4 male and 1 female cadaveric donors without gross meniscal pathology (age = 62.4±2.61 yrs). The specimens were placed in perfluorooctyl bromide solution to minimize susceptibility artifacts from air-tissue interface during MR imaging. ***MR Imaging.*** UTE images were acquired using 2D projection-reconstruction sequences[2]. Coronal images were taken with a 3T GE Signa HDxt MR scanner in a 1.5" solenoidal coil where the main circumferential collagen fibers were oriented perpendicular to B0 in order to avoid any magic angle effects. Imaging parameters were TR 300 ms, TE 10 µs and 12 ms, FOV 4 cm, matrix 512x511, FA 45°, BW ±31 kHz, number of excitations (NEX) 2, and 1mm slice thickness. ***Indentation Testing***. The specimens were vertically placed in tailored plastic frame to inhibit movement and significant lateral expansion during indentation testing. Femoral and tibial articular surfaces of each specimen were compressed with a 1.0 mm diameter plane-ended cylinder indenter, to a depth of 100 µm over 1 s while the peak force (g) was measured. Indentation was performed at multiple sites 1.0 mm apart on each surface (Fig.1A). ***Image Analysis***. MR images were reviewed for the presence of lamellar layer thickening. Abnormal thickening of lamellar layer was defined as localized thickening with uneven articular surface. Lamellar layer thicknesses were measured at sites, using OsiriX software (Fig.1B). ***Statistics.*** Correlation between the thickness and indentation property were assessed using a Pearson's correlation test. Interobserver reliability for measurement of lamellar layer thicknesses between two radiologists was examined using an intraclass correlation coefficient (ICC).

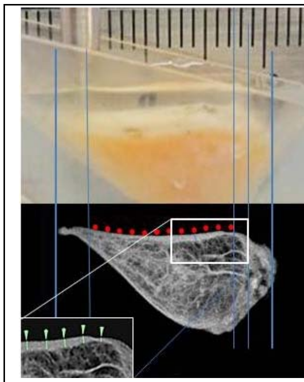

Fig.1: (**A**) Indentation test. (**B**) Thickness measurement at corresponding sites on UTE image.

RESULTS: Interobserver reliability for measurement of lamellar layer thicknesses was excellent (ICC=0.942). Eight lamellar layers with normal morphologic feature had thickness of 247±104 µm (mean±SD) with a range of 110 to 582 µm) and stiffness of 0.925±0.876 g with a range of 0.0673 to 4.93 N/mm); for femoral lamellar layers, thickness 295±107 µm (range, 109.5~425.2 µm) and stiffness 0.915±.0.*853* g (range, .0673~3.72 g); for tibial lamellar layers, thickness 226.±96.0 µm (range, 132~582 µm) and stiffness 0.944±.895 g (range, 0.105~4.93 g). Femoral lamellar layers were significantly thicker than tibial ones (p=0.004), but there was no significant difference in stiffness. Two femoral lamellar layers with abnormal thickening had mean thickness of 4.72±0.73 µm and mean stiffness of 0.613±0.437 g. Lamellar layer thicknesses significantly correlated with indentation stiffnesses (r=0.493~0.839, all p<0.05 except one layer with p=0.075) (Fig.2A,B,C) except two abnormally thickened femoral layers, one of which showed strong negative correlation (r=-0.902, p<0.001) (Fig. 3A,B,C) and the other showed no significant correlation.

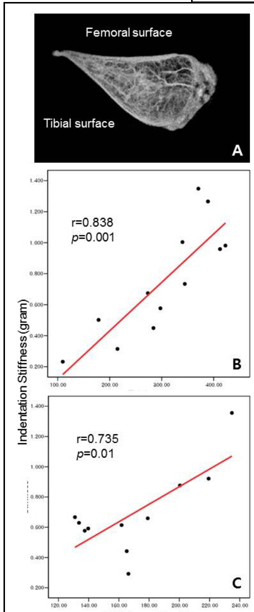

Fig.2: Normal lamellar layer on 2D UTE image (A) and correlation between lamellar layer thickness and indentation stiffness for femoral (B) and tibial surface (C).

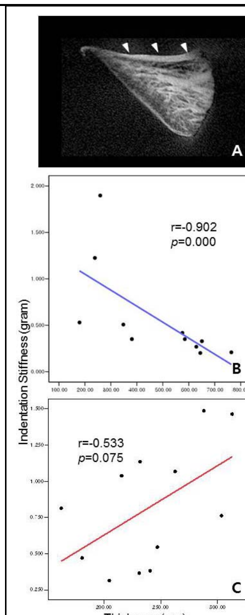

Fig.3: Abnormally thick femoral lamellar layer (A) and correlation between lamellar layer thickness and indentation stiffness for femoral (B) and tibial surface (C).

DISCUSSION: Our results suggest that if lamellar layer maintains normal morphology on UTE images, the thicker lamellar layer is, the higher the stiffness is. We speculate that lamellar layer thickness may play a role in shock absorption with a protective role against extrinsic stresses and extension of intrameniscal pathology such as tears to the articular surface. The lower stiffness of abnormally thickened lamellar layer may indicate degenerative change results in loss of integrity of material property.

CONCLUSION: Variation of lamellar layer thickness in normal human menisci was evident on 2D UTE images, and femoral lamellar layers were found to be significantly thicker than tibial ones. Moreover, the thickness significantly correlated with surface indentation stiffness.

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2. Peter D. Gatehouse, Rhidian W. Thomas, et al. Magnetic resonance imaging of the knee with ultrashort TE pulse sequences. Magn Reson Imaging 2004;22(8):1061-1067.