MRI of the Cartilaginous and Fibrous Structure of the Meniscus of the Knee: In Vitro Studies at 11.7T

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Target Audience: MR scientists and radiologists interested in the structure and function of the meniscus.
Purpose: To image human and bovine meniscus using high field microscopy in order to define its cartilaginous and fibrous regions and demonstrate different fiber groups so that these features can be related to function in health and disease.
Introduction: The meniscus of the knee is a complex tissue which distributes mechanical load from the body and thereby protects the adjacent articular cartilage. This is achieved with a mixed cartilaginous and fibrous structure with the cartilaginous regions resisting compression, and the fibrous regions resisting tension. The more cartilaginous and more fibrous regions of the meniscus have not been separately visualized with in vivo or in vitro MRI. Classical anatomic descriptions of the fibers based on light and electron microscopy are well known[1], but the fiber patterns described are not seen with MRI in vivo, and do not correspond well with the patterns seen with in vitro MRI studies. In order to more fully demonstrate the cartilaginous and fibrous structure of the meniscus in vitro studies of human and bovine menisci were performed at 11.7T.
Materials and Methods: Four fresh human menisci and six bovine menisci were harvested and frozen in accordance with institutionally approved protocols. An 11.7T system, Bruker BioSpec (Billerica, MA) with 750 mT/m gradients was used. 2D multislice multiecho (MSME) pulse sequences (TR= 30000 ms, TE=8,16 ms) of voxel size 50-70 x 50-70 x 500 μm were employed together with 3D multi-gradient echo (MGE) sequences (TR=80 ms TE=2-18 ms, FA=14°). Specimens were examined in 72 and 38 mm T/R resonators, a four element rat brain array coil and a solenoid (12 mm diameter). The plane of the meniscus was perpendicular or parallel to Bo.
Results: The more central and superficial cartilaginous regions were clearly differentiated from the more internal and peripheral fibrous regions (Fig. 1). Marked magic angle effects were seen in the fibrous regions of the meniscus. When the circumferential fibers were parallel to Bo a low signal was seen within them, with a higher signal from the radial fibers when they were perpendicular to Bo. Braided and woven appearances of circumferential fibers were seen. These overlapped and crossed typically at the junctions of the body of the meniscus with the anterior and posterior horns. Oblique circumferential fibers were also seen. Vertical fibers were apparent when Bo was perpendicular to the plane of the meniscus. Oblique vertical fibers were also seen. Curved fibers adjacent to the more cartilaginous parts of the meniscus were also observed. Both radial ties and sheets were seen. Blood vessels were seen between circumferential and radial fibers (Fig. 2).

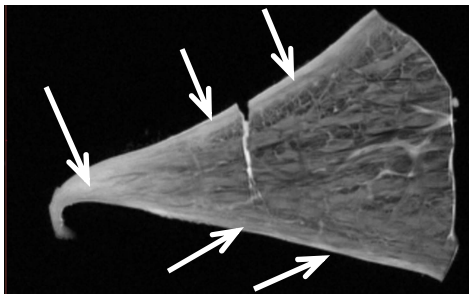

Fig. 1 Human meniscus in radial plane. Bo perpendicular to image plane, MSME sequence. Cartilage is seen centrally and at the femoral and tibial surfaces (arrows). (A surgically induced tear is seen centrally.)

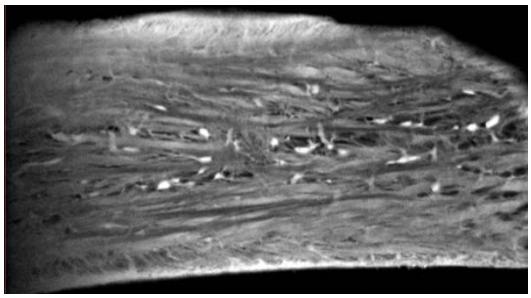

Fig. 2 Bovine meniscus in sagittal plane. Bo runs left right on the image, MSME sequence. Blood vessels are visualized with high intensity, interspersed between low signal circumferential fibers and intermediate signal radial fibers.

Discussion: Clear differentiation between more cartilaginous and more fibrous regions of the meniscus was seen in regions corresponding to previous studies using Safranin-O staining to detect cartilage. Vertical fibers, curved fibers and oblique circumferential, radial and vertical fibers were also seen. These fiber groups do not feature in classical illustrations of the fiber structure of the meniscus. Cartilage was most evident centrally where compressive forces are probably maximal. Circumferential fibers anchored to the tibia through root ligaments were seen at the periphery where they resist tension. The vertical fibers resist translation in the superior-inferior direction. Oblique fibers resist shear forces in different directions. There has been controversy over whether radial ties are in the form of fibers or sheets[2]. Both patterns were observed in this study. Some of the features seen here have been observed with optical projection tomography providing general confirmation of the findings[3], although oblique and curved fibers adjacent to cartilage were not described. High resolution MRI provides a more complete basis for understanding the structure and function of the meniscus as well as demonstrating features which may be visible at higher field strengths using clinical systems.

References

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