Dynamics of articular joints visualised by MRI: joint flexion, cartilage-compression and solute-perfusion

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Since articular cartilage is avascular, the continued viability of the chondrocytes, and hence of the cartilage structure, depends on the mass transport of nutrients from the synovial fluid into the cartilage and of proteoglycan from the chondrocytes. Although those processes have been studied for isolated specimens (Maroudas 1970, Urban 1992, Burstein et al. 1993), in an intact joint the effects of joint flexion and extension, and of the associated waves of cartilage compression, can be expected to enhance what would otherwise be a passive, diffusive process. In anticipation of making such studies we demonstrate here in-vivo the visualisation by Magnetic Resonance Imaging (MRI) of joint flexion/extension and of cartilage compression, and ex-vivo the perfusive diffusion of organic molecules through an intact articular joint.

Methods

All measurements were made using a 31 cm horizontal bore magnet operating at either 2.0 or 2.4 Tesla, controlled by a Bruker Biospec II console. The experimental data were processed using CaMReS software written in C-code by Dr N J Herrod, running on UNIX workstations.

Flexion-extension of the proximal interphalangeal joint

MRI has previously been used to follow the flexion of articular joints such as the knee (Deutsch et al. 1991). Figure 1 demonstrates the time and spatial resolution possible for equivalent studies of the proximal-interphalangeal joints; approximately 50 such images can be obtained within a total of 30 minutes. Although the spatial resolution of 230 µm x 230 µm and slice thickness of 2 mm is compromised by the need for acceptable time resolution, it is adequate to delineate the relative location of the two bones, of the tendons, and of the cartilage on the articular surfaces. It is interesting to note the movement of the flexor tendon against the volar plate, and the distortion of the latter during the flexion-extension cycle.

Compression of the distal interphalangeal joint

It is known that compression of cartilage expresses water from the matrix (Mow et al. 1984). For damaged knee cartilage, this can be measured as the reduction of joint-space visualised by radiographs of the knee when it is loaded as compared with its unloaded spacing. We have been able to detect a reversible loss of signal intensity from the cartilage water of the distal-interphalangeal joint using high spatial resolution MR imaging following loading. The imposed pressure of ~ 800 KPa was in the range of normal loading in weight bearing joints (Weightman and Kempson 1979). Full interpretation of the observed loss of signal intensity will require accurate measurement of the other MRI parameters of the cartilage-water to determine if the reduced signal intensity is due to water loss or (more probably) to changes in the matrix-water interactions.

Solute perfusion through cartilage

Although Maroudas (1970) and others (Urban 1992, Burstein et al. 1993) have reported rates for the perfusion of solutes through cartilage ex-vivo, to the best of our knowledge equivalent measurements have not been made for an intact joint. The approach adopted here depends on the fact that a stable nitroxide free radical such as 4-hydroxy-2,2,6,6-tetramethylpiperidine-1-oxyl (4-hydroxy-TEMPO) shortens the relaxation times of the protons of water. Consequently an

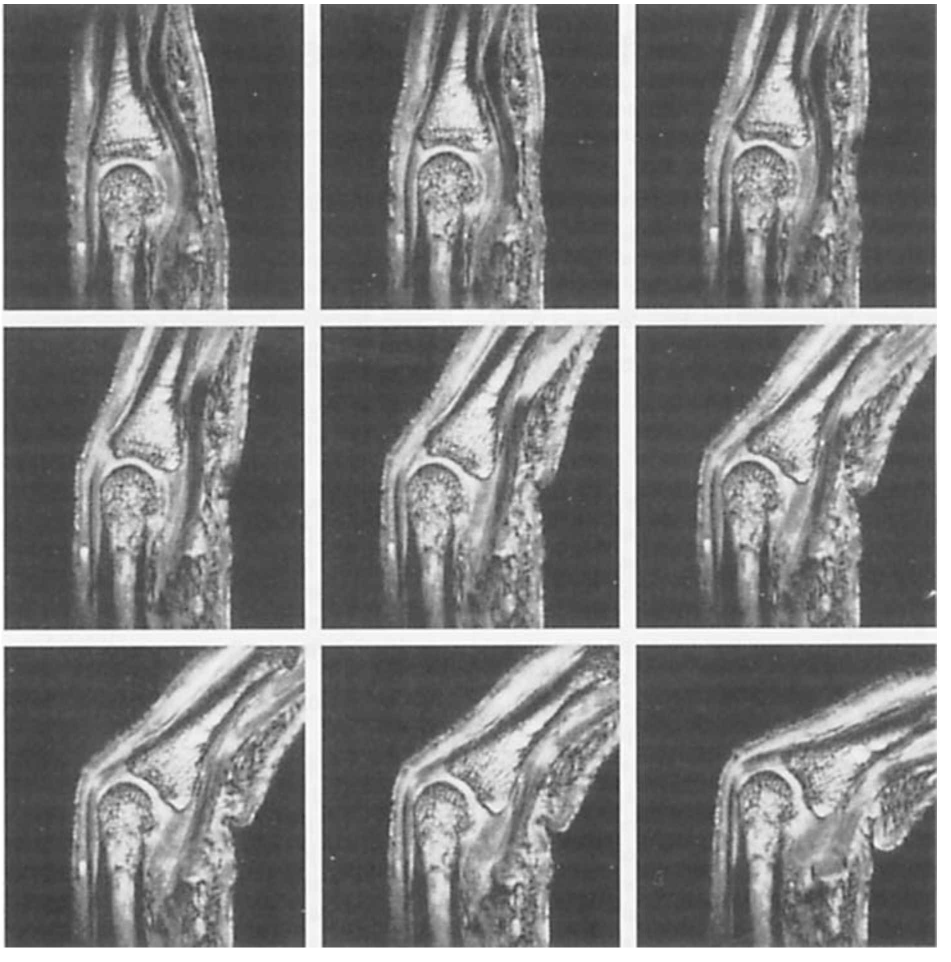

Figure 1. MR images of the index finger of an 25-year-old man, showing 9 different stages of flexion.

MRI sequence sensitised to the T1-value of the cartilage of a hen-knee (Figure 2) shows where the radicals are located, and hence enables its diffusive perfusion from the synovial fluid to be followed.

If the nitroxide is allowed to establish an equilibrium distribution throughout the cartilage, then it can act as an "indicator" for the location of any agent which can reduce the nitroxide free radical. Thus the diffusion of ascorbic acid through cartilage can be followed.

Discussion

The three independent sets of measurements summarised above demonstrate the potential use of MRI to evaluate the effects of articulation on the perfusion of organic molecules through the cartilage of an intact joint. A study of flexion can clearly delineate which sections of the articular cartilage make contact during the course of the joint articulation; this is important as it would be expected that uptake of solutes from the synovial fluid should be favoured in those regions. Visualisation of the effects of compression on those same regions may indicate the local structure of the cartilage matrix.

Since the low signal-to-noise sensitivity of MRI prevents direct visualisation of organic solute molecules, the indirect method proposed here based on use of nitroxide free radicals as "molecular amplifiers" may provide useful insight to diffusion processes in the cartilage of the intact articular joint.

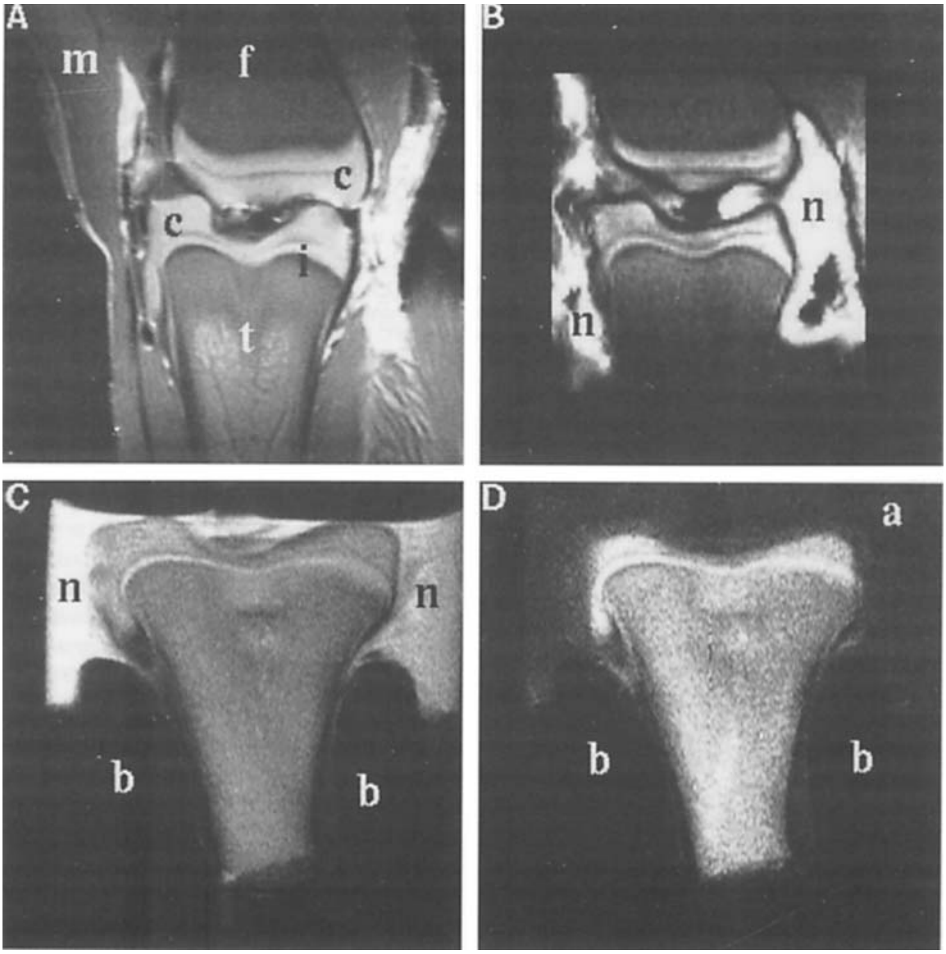

Figure 2. MR images of the same intact hen knee joint. A, the intact joint. B, following the partial perfusion of nitroxide through the cartilage. For a disarticulated joint, C, after perfusion of through the cartilage into the bone marrow. D, after partial perfusion of ascorbic acid.

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