ASSESSMENT OF ARTICULAR CARTILAGE USING MAGNETIC RESONANCE IMAGING

ABSTRACT

Articular cartilage lesions are common problems and imaging diagnosis techniques is increasingly important. MRI is the imaging method of choice for evaluation of chondral lesions. This article analyzes the utility of this method by reviewing conventional as well as advanced quantitative studies on early assessment of chondral alterations before being evident in routinely performed MRI sequences.

Keywords: Articular cartilage, chondral lesions, magnetic resonance imaging.

INTRODUCTION

Articular cartilage lesions are common problems in various joints; they have multifactorial etiologies, which encompasses traumatic causes, inflammatory and infectious (septic arthritis) arthropathies, and degenerative causes. Lesions of degenerative origin are the most common entities and constitute an important public health issue due to the heavy economic and social burden posed by treatments and absence from work. An estimated 75% of the population over 75 years of age have osteoarthritis (1).
The articular cartilage or hyaline cartilage is of vital importance in synovial joints (with wide range of motion) and its main functions are to dissipate energy and transmit forces into joint surfaces, to cushion loads and provide an appropriate sliding surface between joint surfaces. The main features of the hyaline cartilage are summarized as follows: it is a avascular tissue (nourished by synovial fluid); it contains no innervation; it has no ability to regenerate with the same tissue; it exhibits limited reparative capacity with fibrocartilage, which is less resistat. The articular cartilage is composed of the following elements (Figure 1):

A. **Water** (65-80%): More abundant in surface portions of the cartilage and its content increases with the aging process and with degenerative changes.

B. **Collagen** (10-20%): The predominant collagen is of type II (95%); it is the supportive matrix of the cartilage and provides resistance to tension forces. Collagen is the main component in dehydrated cartilage.

C. **Proteoglycans** (10-15%): They are produced by chondrocytes, being glycosaminoglycans (GAGs) its subunits. They provide resistance to the forces of compression and posses elastic resistance.

D. **Chondrocytes** (5%): They are the only cells found in the cartilage and are responsible for producing proteoglycans, collagen, proteins and certain enzymes.

**Figure** 1. Diagram showing the different components of articular cartilage.
In the articular cartilage, the following different zones can be identified, depending on their depth and collagen fibers orientation (Figure 2): a) The surface portion comprises about 10-20% of the cartilage thickness, and collagen fibers are arranged parallel to the cartilage surface. b) The transitional zone which comprises 40-60% of the cartilage thickness. In this layer, the orientation of collagen fibers appears more random. c) The deep 30% of cartilage is termed the radial zone; it is characterized by a preferential orientation of collagen perpendicular to subchondral zone. It is the zone where the interlaced framework of collagen fibrils is more compact. d) Finally, the calcified outer layer corresponds to the zone where cartilage fuses to the articular cortical bone.

Processes of aging and degeneration of articular cartilage are associated with loss of reproductive ability of chondrocyte, decreased levels of proteoglycans, cartilage stiffness, and increased water content. These alterations together determine changes in both cartilage features and functions, turning it less resistant and prone to injuries, ulcerations, and fissures.

Figure 2. Diagram of the different zones of articular cartilage, depending on collagen fibers orientation.
From both imaging and arthroscopic approaches, several classifications of chondral lesions can be found. In this context, a proper communication with clinicians, specially with traumatologists, is necessary and radiologists are required to use standard classifications known and employed by them. When necessary, classifications (mainly arthroscopic) should be modified in our imaging reports. One of the classifications most commonly used by clinicians dedicated to chondral lesion issues is the ICRS (International Cartilage Repair Society) Classification (Table 1). This arthroscopic classification is easy to extrapolate to our imaging studies since it is primarily based on lesion depth.

### Table 1. ICRS Classification (International Cartilage Repair Society) of chondral lesions

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
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<tbody>
<tr>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>1 A</td>
<td>Superficial fibrillation or softening</td>
</tr>
<tr>
<td>B</td>
<td>Superficial fissures and lacerations</td>
</tr>
<tr>
<td>2</td>
<td>Defect &lt;50%</td>
</tr>
<tr>
<td>3 A</td>
<td>Defect &gt; 50% without extending down to calcified layer</td>
</tr>
<tr>
<td>B</td>
<td>Defect &gt; 50% extending down to calcified layer</td>
</tr>
<tr>
<td>4 A</td>
<td>Total defect involving subchondral plate</td>
</tr>
<tr>
<td>B</td>
<td>Total defect with deep involvement of subchondral plate</td>
</tr>
</tbody>
</table>

Magnetic resonance imaging (MRI) is the method of choice for assessing articular cartilage lesions due to its non-invasiveness, high contrast resolution, and multiplanar capability.

MRI performance in detecting chondral lesions depends on the equipment used; high-field 1.5 or 3 Tesla scanners appear to be the best option for evaluating
articulard cartilage lesions. Sensitivity of MRI correlates with extension of involved chondral surface as well as with lesion depth (2). On the other hand, thicker cartilages such knee cartilages, are easier to evaluate than those of smaller joints.

It is of great importance to carry out directed searches of chondral lesions at articular MRI exams, since it is usual that when conducting retrospective reviews to be compared with surgical findings, injuries that went unnoticed in the first reading may be visualized. Characteristics of chondral lesions that must be clearly informed in MRI reports, especially when they are focal and unique, are summarized in Table 2.

Table 2. Important features of focal chondral injuries to be reported.

1. Surface extension measuring anteroposterior and transverse extension.
2. Lesion depth (percentage of cartilage thickness involvement).
3. Location on articular surface (involvement of weight-bearing zone).
4. Subchondral bone alterations (edema, cysts)
5. Intra-articular chondral or osteochondral bodies.

Several studies have been published trying to elucidate which are the most useful sequences for evaluation of articular cartilage. Sequences with high contrast between cartilage and liquid and between cartilage and subchondral bone are appropriate for assessing chondral pathology. Sequences that best meet these contrast conditions are particularly fat-suppressed PD FSE and fat-saturated T1 SPGR images. In fat-saturated DP FSE images, the cartilage has intermediate signal intensity, fluid presents high signal intensity and subchondral bone has low signal intensity (Figure 3). In fat-suppressed T1 SPGR, cartilage signal intensity is high, while liquid and subchondral bone have low signal intensities (Figure 4). This last sequence performed with 3D technique produces thin slices.
Figure 3. Axial fat-suppressed proton density-weighted imaging showing patellar cartilage. Cartilage is of intermediate signal intensity in contrast to the high-signal intensity joint fluid.
Axial SPGR T1-weighted image showing patellar cartilage and femoral trochlea. Cartilage is of high signal intensity, while joint fluid has low signal intensity.

T2-weighted images show good contrast between cartilage (low signal intensity) and fluid (high signal intensity); however, contrast between cartilage and subchondral cortical bone is not appropriate as both have low signal intensity. Although this sequence is not sensitive enough to subtle changes, it is important in traumatic chondral lesions.

There is consensus on considering fat-suppressed PD FSE and fat-saturated T1 SPGR images as the most useful sequences. They provide good contrast and sensitivity to pathological changes of the articular cartilage.

As previously mentioned, it is important to perform directed search for cartilage lesion, independent of the protocol used for the study.

Chondral lesions of traumatic origin are typically solitary, with well-defined contours, often affecting the full thickness of the cartilage (Figure 5), and may be associated with intra-articular osteochondral or chondral bodies, which may cause locking of the joints. Lesions of degenerative origin initiate with intrasubstance biochemical alterations, continuing with fibrillation, fissures, full-thickness ulcerations, and finally, full-thickness loss of cartilage. Usually, degenerative lesions have irregular contours and often involve more than one area of articular surfaces with lesions of varying thickness. Depending on stage of involvement,
secondary arthritic changes, such as marginal osteophytes, cysts, and signal intensity alterations of subchondral bone may be seen (Figure 6).

Figure 5. Sagittal fat-saturated proton density-weighted image of external femorotibial compartment of the knee (a) and T2 (b). A full-thickness traumatic focal
chondral lesion can be seen.

Figure 6. Axial fat-saturated proton density-weighted image showing advanced degenerative chondropathy of the patella.

MRI is important in evaluating chondral injuries treated surgically. In this context the two most commonly used surgical techniques are microfracture and autologous osteochondral grafts (Mosaicplasty, OATS). Microfracture is a technique that involves making multiple perforations in the area of chondral lesion resulting in a bloody area of subchondral bone with formation of a group of undifferentiated mesenchymal cells that will generate reparative fibrocartilage, which is less resistant than the hyaline cartilage. Autologous osteochondral graft technique, primarily used in chondral lesions on weight-bearing surface of the knee, involves removing a osteochondral fragment from a non-weight-bearing area (usually femoral trochlea) to be placed in the original site of chondral injury. This procedure, despite being technically more demanding, has the advantage of repairing the lesion with hyaline cartilage.
RMI ADVANCED STUDIES

Special MRI methods have been developed for evaluation of articular cartilage. Most of them are studies that remain under investigation rather than having important clinical application, except for T2 mapping, which has been developed mainly through daily practice. T2 mapping will be thoroughly reviewed in this paper.

T2 MAPPING

T2 mapping of the articular cartilage is a quantitative method for evaluating the internal structure of the cartilage. With this technique it is possible to measure the T2 relaxation time of cartilage.

T2 relaxation times in normal cartilage decrease in the deeper layers, where the interlaced framework of cartilage fibers is more compact and there is less water. T2 relaxation times increase toward the more superficial zones of the cartilage.

This method is essentially based on the fact that degenerative changes cause disorganization of the collagen matrix, which becomes less elastic allowing increased levels of H2O proton content and motion which in turn results in increased T2 relaxation values over normal levels.

With the right program at the workstation, it is possible to measure T2 relaxation time in milliseconds, placing the area of interest where deemed necessary, so allowing to quantify alterations objectively. Besides, this can be represented morphologically in color imaging by using a predefined scale to make it visually detectable (Figure 7). As this is a quantitative rather than morphological study, this technique is of great usefulness in detecting early alterations in cartilage intra-substance, prior to ulcerations and fissures of cartilage surface (Figure 8).

Through this method, evolution of incipient chondral alterations after drug treatments or other kind of therapies can be assessed. Among the most advanced techniques for cartilage evaluation, T2 mapping is increasingly being used in current clinical practice (4,5,6).
Figure 7. T2 mapping with color scale of normal patellar cartilage, where deepest zone is in red and indicates low levels of T2 relaxation time; central zone is in yellow, while superficial area is in green, showing higher T2 levels.

Figure 8. T2 color map on two different patients showing altered areas (arrows)
with increased T2 levels of articular cartilage thickness.

**DELAYED REINFORCEMENT WITH GADOLINIUM**

This method involves injecting negatively-charged ionic gadolinium intravenously to subsequently perform active mobility exercises on the target joint to allow passage of contrast material into synovial fluid. This method permits evaluation of proteoglycan concentration of articular cartilage (7).

This study is based on the negative charges of glycosaminoglycans, i.e., proteoglycan subunits. It is known that there is a decrease in proteoglycan levels due to degenerative and aging processes of the articular cartilage. If there is a normal amount of glycosaminoglycans (negatively charged), the contrast agent (negatively charged) will be repelled and will not penetrate into the cartilage by diffusion. When the level of glycosaminoglycans is reduced, the contrast agent may penetrate and permeate damaged areas of the cartilage. This increased content can be represented in color images.

Among other advanced exploration methods, primarily used in research rather than in clinical application, we can mention specific techniques, such as short echo time (TE) projection reconstruction magnetic resonance (MR) imaging and spectroscopy of cartilage.

In summary, the articular cartilage is a highly resistant tissue; however, its injuries are frequent and MRI is the imaging method of choice for its evaluation. The conventional sequences are useful, but there are also some other specialized MRI techniques capable of yielding more objective and quantitative assessment of incipient degenerative chondral changes. Several of these special techniques are still under research and have not yet been applied to current clinical practice. The exception is T2 mapping of articular cartilage which is increasingly being used in current clinical practice.
REFERENCES


