Articular cartilage: Evaluation by magnetic resonance

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Keywords: Articular cartilage, Magnetic resonance.

Articular cartilage lesions are common in various joints and their multifactorial etiologies, including traumatic causes, inflammatory and infectious (septic arthritis) arthropathies and degenerative causes. Lesions of degenerative origin are the most frequent, being an important public health problem due to the high economic and social costs that represent the direct or indirect spending in relation to treatment and absence from work. It is estimated that approximately 75% of the population over 75 years of age have osteoarthritis(1).

Articular cartilage consists of (Figure 1):

A. Water (65-80 %): it is present in greater quantity in the superficial portions of the cartilage and its content increases with the aging process and with degenerative changes.

B. Collagen (10-20%): the predominant collagen is type II (95%), corresponding to the support matrix of the cartilage and provides resistance to tension forces. Collagen is the primary component in dehydrated cartilage.

C. Proteoglycans (10-15%): are produced by chondrocytes, glycosaminoglycans (GAG) being its subunits. They provide resistance to compression forces and have elastic resistance.

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

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Its water content increases. Together these alterations determine loss of the characteristics and functions of the cartilage, making it less resistant and prone to injury from fissures and ulcerations.

It is possible to find various classifications of chondral lesions, not only from an imagenological but also an arthroscopical viewpoint. Therefore communication with clinicians is important, especially orthopedists, as radiologists must use classifications that are known and used by clinicians who interact with us and if necessary adjust the basic arthroscopic classifications to our imaging reports. One of the key classifications most used by clinicians dedicated to the issue of chondral lesions, is the classification by the ICRS (International Cartilage Repair Society) (Table I). This arthroscopic classification is easy to compare to our imaging studies, as it based primarily on the depth of the lesion.

Figure 1. Diagram showing the various components of articular cartilage.

In the articular cartilage different zones are identified depending on the depth and collagen fiber orientation (Figure 2). Thus, a surface or superficial zone that covers about 10 to 20% of the thickness of cartilage is recognized where the collagen fibers are arranged parallel to the cartilage surface. The transitional zone corresponds to 40 - 60%, where collagen fibers are randomly arranged. In the deep or radial zone, corresponding to approximately 30%, the collagen fibers are arranged perpendicular to the surface and it is the zone where the interlaced framework of collagen fibrils is more compact. Finally, the calcified sheet (zone), corresponding to the zone where the cartilage is fused to the articular cortical bone.

Table I. ICRS (International Cartilage Repair Society) classification of chondral lesions.

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

The aging processes and degeneration of the articular cartilage are associated with loss of reproductive capacity of the chondrocytes and the reduction of proteoglycans. Cartilage becomes more rigid and its water content increases. Together these alterations determine loss of the characteristics and functions of the cartilage, making it less resistant and prone to injury from fissures and ulcerations.

Magnetic resonance imaging (MRI) is the method of choice for evaluating articular cartilage lesions as it is non-invasive, has high contrast resolution and multi-plane capability.

MRI performance in the detection of chondral lesions will depend on the equipment used, high field 1.5 or 3 Tesla resonators being necessary for the evaluation of articular cartilage lesions. It is important to use appropriate protocols and sequences to identify subtle lesions (Figure 3). The sensitivity of the MRI is directly proportional to the magnitude in terms of the involved chondral surface and the depth of the lesion. Furthermore, thicker cartilage such as that of the knee, is easier to evaluate than the cartilage of smaller joints. It is important, always and in all articular MRI studies, to conduct a directed search for chondral lesions, as it is usual when reviewing retrospectively and comparing with surgical findings, to see lesions that were not apparent during the first reading. The
chondral lesion characteristics, especially when focal and unique, which we must specify in the MRI report, are summarized in Table II.

Table II. Important characteristics to report in a focal chondral lesion.

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

Much has been published regarding the most useful sequences in the evaluation of articular cartilage. Sequences with good contrast between the cartilage and fluid, and with good contrast between cartilage and subchondral bone, are appropriate for the evaluation of chondral pathology. Sequences that best meet these contrast conditions are specifically fast spin echo proton density enhanced (FSE PD) with fat suppression and T1 gradient sequences (T1 SPGR) with fat saturation. In FSE PD with fat saturation, cartilage is seen with intermediate signal intensity, the fluid with high signal and subchondral bone with low signal (Figure 4). In T1 SPGR with fat suppression, the cartilage is seen with high signal, and the fluid and subchondral bone have low signal intensity (Figure 5). This last sequence performed with 3D technique, allows thin slicing.

Figure 3. High-resolution coronal T2 slice image using 1.5 Tesla unit, shows small superficial lesions (arrows) in cartilage of the medial compartment of the knee. Sagittal T2 slice image on 3 Tesla unit shows thin traumatic lesion of the tibial plateau cartilage (arrow).

Figure 4. Proton density enhanced axial slice with fat suppression, showing the patella cartilage. The cartilage has an intermediate signal in contrast to the articular fluid high signal.

Figure 5. Gradient sequential T1-weighted SPGR axial image showing the patellar cartilage and femoral trochlea. Cartilage signal is high in contrast to the articular fluid with a low signal.
T2 sequences have good contrast between cartilage (low signal) and fluid (high signal), however, the contrast between cartilage and subchondral cortical bone is not suitable, since both have a low signal. Although this sequence is not very sensitive to subtle changes, it is important in traumatic chondral lesions.

There is considerable consensus that the most useful sequences are FSE PD with fat suppression and T1 SPGR with fat saturation\(^{(3)}\). These sequences have good contrast and are sensitive to pathological changes of the articular cartilage, which makes them the best sequences. As mentioned previously, it is important to conduct a directed search for cartilage lesions, independent of the protocol used for the study.

Chondral lesions of traumatic origin are typically solitary and with well defined contours. They often involve the whole cartilage thickness (Figura 6) and can be associated with intra-articular chondral or osteochondral bodies, which can cause joint locking. Lesions of degenerative origin begin with intrasubstance biochemical alterations, followed by fibrillation, fissures, full-thickness ulcerations and finally total loss of the complete cartilage thickness. Usually the degenerative lesions have irregular contours and often involve more than one area of the articular surfaces with lesions of variable thickness. Depending on the stage of involvement, secondary osteoarthritic changes such as marginal osteophytes, cysts and alterations of the subchondral bone signal can be observed (Figure 7).

The MRI is important in evaluating surgically treated chondral lesions. In this sense the two most frequently used surgical techniques are microfracture and autologous osteochondral grafts. Microfracture involves drilling in the area of the chondral lesion, which induces bleeding of the subchondral bone with the formation of undifferentiated bone marrow mesenchymal cell clusters that will produce the reparative fibrocartilage, which is of lower resistance than hyaline cartilage. Autologous osteochondral grafts are used mainly in chondral lesions on weight-bearing surfaces of the knee, which consists in taking an osteochondral fragment from a non-weight-bearing area (usually femoral trochlea) to be placed in the area of the original chondral lesion. This procedure, although more demanding technically, has the advantage of repairing the lesion with hyaline cartilage.

**MRI advanced studies**

Special methods of MRI have been developed for the evaluation of articular cartilage. The majority of these are studies that remain mainly in research, without important clinical application, the exception being the T2 mapping study, which has been developed mainly in daily practice and will be reviewed in more detail.

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**Figure 6.** Sagittal slice images of the external Tibiofemoral compartment of the knee, PD enhanced with fat saturation (a) and T2 (b). A full thickness focal chondral lesion of traumatic origin can be seen.

**Figure 7.** Axial PD enhanced fat saturated image, showing advanced degenerative chondropathy of the patella.
The articular cartilage T2 mapping, 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 the cartilage.

T2 relaxation times in normal cartilage are lower in the deeper layers where interlacing of cartilage fibers is more compact and there is less amount of water. T2 relaxation times increase toward the more superficial areas of cartilage.

This method is based mainly on the fact that degenerative changes produce disorganization of the collagen matrix, which becomes more relaxed allowing higher content of H2O protons which are also freer, producing an increase in T2 relaxation values, over normal levels.

With the right program, at the work station it is possible to measure the T2 relaxation time in milliseconds, placing the area of interest where deemed necessary, allowing objective measurement of alterations. Furthermore this can be represented morphologically in color image, using a predefined scale to make it visually detectable (Figure 8). As this is not a morphological study, but more so quantitative, its main use is to detect initial intrasubstance alterations of the cartilage, before ulcerations or fissures on its surface (Figure 9). This capability enables this method to evaluate the evolution of emerging chondral alterations after pharmacological treatments or others. Of the more advances techniques for cartilage evaluation, this is the one which is being most used in clinical practice(4-6).

Delayed gadolinium reinforcement
This method involves intravenously injecting ionic gadolinium, which has negative charges, and undertaking active movements and exercising the articulation under study to allow the contrast to pass into the synovial fluid. This method allows evaluation of the proteoglycans concentration in the articular cartilage(7).

This study is based on the negative charges that the glycosaminoglycans have, which are subunits of the proteoglycans. It is known that the degenerative and aging processes of articular cartilage decreases the amount of proteoglycans. If there is a normal amount of glycosaminoglycans (negative charge), the contrast (negative charge) will be repelled and will not diffuse into the cartilage. When the amount of glycosaminoglycans is reduced, it allows the contrast to penetrate and permeate the cartilage in the affected areas. This increased uptake can be represented in color image.

Among other advanced study methods and used mainly in research more so than in clinical application, we can mention specific techniques such as short echo time projection reconstruction and cartilage spectroscopy.

Summary
The articular cartilage is a highly resistant tissue. However, lesions are frequent and MRI is the method...
of choice for image evaluation of these. Conventional sequences are useful for this, although some other specialized MRI techniques exist that can allow a more objective, quantitative evaluation of the emerging degenerative chondral alterations. Several of these special techniques are still in the process of development and investigation and have not yet been applied to clinical practice. An exception to this is the T2 mapping of articular cartilage, which it is being used more routinely.

Bibliography