Specialty area: Advanced Cartilage Imaging

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Highlights

- Morphologic MR imaging of articular cartilage, while limited by spatial resolutions constraints, can provide images for accurate assessment of articular cartilage for treatment planning.
- Clinical reports of articular cartilage should be tailored to match the clinical situation.
- Detailed descriptions of articular cartilage defects are important when surgical repair is contemplated.

TALK TITLE - "Clinical Applications"

TARGET AUDIENCE – Clinicians and Researchers interested in imaging of articular cartilage

OUTCOME/OBJECTIVES – Attendees will gain an understanding of the diagnostic and technical challenges facing radiologists in their morphologic assessment of articular cartilage on routine clinical MR studies. Clinical examples will be presented that the highlight of MR appearances of cartilage abnormalities and useful imaging techniques.

ABSTRACT – Accurate MR imaging of articular cartilage has greatly improved over the years, but remains challenging[1]. Since articular cartilage is thin and its surface contour is curved, high resolution images with thin slices are critical to reduce partial volume averaging artifacts. It is important to use as small a field of view and as high an imaging matrix as signal-to-noise ratio (SNR) will allow. High field strength MR systems with the best possible radiofrequency coils are required to obtain adequate for optimal spatial resolution images. Scanning at field strengths, ≥1.5Tand preferably 3T, is desirable. In general, open design, i.e. "clamshell." scanners have lower field strength and field homogeneity resulting in lower SNR than cylindrical magnet systems. A variety of multichannel phased array coils have been developed specifically for knee, foot and ankle, hand and wrist, shoulder, and hip. Use of a dedicated coil is recommended whenever the patient's anatomy allows. Imaging of cartilage in the deeper joints like the hip and shoulder is often limited by technical factors including lower SNR and image artifacts from phase wrap.

Although many cartilage pulse sequences have been developed, fast spin echo (FSE, TSE) techniques have emerged as the most commonly used imaging acquisitions for clinical purposes; in part, this is because these sequences are also useful for assessment of non-cartilaginous joint structures [2, 3]. A combination of both fat-suppressed and non fat-suppressed images is desirable since the deep cartilage can be mistaken for suppressed marrow fat if only fat-suppressed images are obtained. The receiver bandwidth should be adjusted to minimize chemical shift artifacts, especially for non fat suppressed images and 3T imaging. If the chemical shift is too great, the cartilage may appear too thin and/or the subchondral bone may appear too thick. The inferior trochlea and posterior weightbearing femoral condyle are especially prone to partial volume averaging artifacts on axial and coronal images because the orientation of articular surfaces to the scan planes. Angled images can help reduce these artifacts.

The introduction of 3D techniques that can produce isotropic (or nearly isotropic) voxels ≤0.7mm with FSE image contrast has greatly improved our imaging. Following a single acquisition, the images may be reformatted in any plane; this capability, in combination with the thin slice thicknesses, can be used to greatly reduce partial volume averaging artifacts[4]. 3D gradient echo techniques, including DESS and fat suppressed T1-weighted spoiled gradient (FLASH, SPGR) are also very useful for cartilage imaging and have become the acquisitions of choice for quantitative analysis of cartilage volume and thickness[4-6]. The technical factors of all pulse sequences should be optimized to highlight the cartilage-fluid, cartilage-fat, and cartilage muscle interfaces.

MR-arthrography can improve the image contrast cartilage-fluid interfaces and potential produce superior cartilage defect detection, however, MR-arthrography requires an injection, either intraarticular (IA) or intravenous (IV), and additional patient time. For most contrast agents, these are off-label use of the agent. For IA injection, the contrast agent needs to be diluted to a 1-2 millimolar solution[7]. An alternative method is IV (indirect) arthrography. With this technique, a standard or double dose of MR contrast is injected intravenously. The patient should be instructed to move the joint through range of motion (e.g. walking) for about 15 minutes before scanning begins to ensure optimal enhancement of all of the joint fluid[8]. I recommend using the standard (noncontast) imaging protocol following the injection unless other information, such as rotator cuff tear, requires specific fat-suppressed T1-weighted images (fat-suppressed T1-weighted images usually have a lower SNR). If a dGEMRIC study is desired, the acquisitions for the T1 map can be obtained following an IV (indirect) arthrogram. The delay for dGEMRIC is usually longer than the post-injection imaging protocol; as the arthrographic effect lasts for over an hour, an additional delay before morphologic imaging starts is often required to ensure an adequate equilibration period is achieved before the T1 map[9].

Since it is difficult for physicians to determine if joint pain is because of a cartilage lesion, it is most important to design the everyday imaging protocols for joints to include image acquisitions that adequately evaluate articular cartilage. With good equipment, this can be achieved while maintaining good patient throughput. Computed tomographic (CT) arthrography (CT-A), *i.e.* CT imaging following IA injection of and iodinated contrast agent, also provides excellent, high resolution imaging of articular cartilage. CT-A may provide an excellent alternative to MR imaging for patients unable to have an MR exam or when evaluation of bone graft is desired. If an IA injection of both a gadolinium chelate and iodinated contrast is given, both a CT-A and an MR arthrogram can be performed following a single injection[10]. In such cases, the CT-A imaging should be performed first since the quality of the CT-A can be more sensitive to dilution/diffusion of the contrast agent.

Normal articular cartilage has a heterogeneous appearance with regional differences in T2 due to the anisotropy of cartilage collagen and the “magic angle effect”[11]. Normal signal varies smoothly across the cartilage while abnormalities show more abrupt differences. The deep regions of articular cartilage normally have low signal on MR images and, on standard images, cannot be visually separated from the subchondral bone. The thickness of the dark “deep cartilage-subchondral bone” region will depend on the TE of the imaging acquisition. The surface of the articular cartilage should appear smooth. The image cartilage surface:joint fluid and cartilage surface:intraarticular fat image contrast is also dependent on

TE. Assessment of the deep and superficial cartilage regions may require more than one type of acquisition.

Injuries may occur at the surface and/or deep within the cartilage[12]. Their appearance depends not only on the depth and type of abnormality, but also on the amount of tissue remaining within the defect. Completely empty defects will be filled with joint fluid and appear similar to fluid while defects filled with damaged tissue may be difficult or impossible to distinguish from normal cartilage by standard morphologic image acquisitions. Cartilage injuries that cause separation between the cartilage and bone, *i.e.* "delamination," may be extensive yet quite subtle, and appear only as a thin bright line at the cartilage-bone interface when the detached cartilage remains in place ("delamination *in situ*").

When describing cartilage abnormalities in a radiologic report, the clinical situation should be considered[13]. For a young patient with a solitary or only a few cartilage defects, treatment with a surgical cartilage repair technique may be an option and a detailed description of each defect is warranted. On the other hand, for an older patient with advanced osteoarthritis, the treatment is more likely to be osteotomy, partial or total joint arthroplasty. In such cases a general description of the cartilage status of each joint compartment is usually adequate; detailed description of each lesion would in a more lengthy report that provides little, if any, additional benefit to the patient and clinician.

Detailed description of a cartilage abnormality should include information that will be useful for treatment planning including the defect location, defect size, status of the defect margins, defect depth, and status of the underlying bone. A structural assessment of the non-cartilage joint structures is also essential. A general description of the type of abnormality is given, *e.g.* fibrillation, fissure, defect, however, there is no universally accepted standard nomenclature for these descriptive terms.

Defect size is usually given as the maximal linear measurements in 2 directions. Often there are regions of damaged, mechanically unstable cartilage at the margins of a defect that would require debridement as part of the cartilage repair surgery. A description of any visible flaps or signal abnormalities in the adjacent cartilage is important. MR imaging may underestimate the size of the full cartilage abnormality found at surgery[14].

Many numeric grading systems have been proposed, most based on a modified Outerbridge system analysis of the depth of the abnormality. For clinical reports, a description of the defect depth such as: "involving only the superficial half of the normal cartilage thickness," "greater than half-thickness," "full-thickness," or "extending into the subjacent bone" may be preferred to reporting a numeric cartilage grade to avoid any confusion between grading systems. Accurate differentiation of the grades of cartilage depth may be difficult because of limited spatial resolution and partial volume averaging artifacts.

The articular cartilage and subchondral bone function as a biomechanical unit and changes in either structure will influence the other. Therefore, evaluation of the subchondral bone plate and subchondral bone marrow is an important part of articular cartilage assessment. The subchondral bone plate may become disrupted with osteochondral lesions; this can be useful in the detection of unstable osteochondral fragments. The subchondral bone plate may thicken forming a central osteophyte (*a.k.a.*

"intralesional" or "button" osteophyte). These osteophytes may need to be removed during surgery, and likely influence cartilage repair outcomes[15]. Edema-like signal in the subchondral bone marrow may develop beneath cartilage defects, especially deep defects[16]. At times, the edema-like marrow signal is more easily detected than the actual cartilage defect. Subchondral cysts may also form beneath cartilage defects. Surgeons may wish to debride or bone graft these cysts; therefore, it is important to indicate their presence. Since they cannot be visualized from the surface at surgery, it is important to indicate where the cysts are relative to the cartilage defect, *e.g.* "An 8 mm deep cyst is located at the anterior margin of the cartilage defect."

In conclusion, MR imaging plays an important role in the diagnosis of articular cartilage abnormalities and treatment planning. Detailed description of defects can provide valuable information to the surgeon when surgical repair is contemplated. Further development of imaging techniques will undoubtedly overcome some of the spatial resolution limitations we current experience.

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