Clinical Application of delayed Gadolinium Enhanded MRI of Cartilage (dGEMRIC)

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Clinical Application of delayed Gadolinium Enhanded MRI of Cartilage (dGEMRIC)

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Introduction

Joint preservation surgery of the hip for young patients with early osteoarthritis (OA) is increasingly recognized as an important therapeutic option. One of the underlying conditions that leads to joint injury is femoroacetabular impingement (FAI) due to decreased head-neck offset. In this condition, the aspherical femoral head causes mechanical damage to the articular cartilage, leading to pain and stiffness, and eventual osteoarthritis. Various surgical treatments exist to successfully treat the underlying bony abnormality of this condition. However, in all cases, the ultimate outcome is highly dependent on the amount of pre-existing articular cartilage damage [1]. Advances in MRI techniques for cartilage imaging have occurred in recent years. Hip imaging is particularly demanding because of the spherical nature of joint, deep anatomical position and the thin articular cartilage. However, advances in coil design and incorporation of parallel imaging has allowed practical application of not only high-resolution morphologic imaging but also some of the newer biochemical imaging techniques for early osteoarthritis.
Due to the importance of the extent of

1 Clinical example of the routinely used T1-weighted 2D coronal Turbo Spin Echo acquisition; images were acquired with the standard surface coil. Resulting voxel size is 0.3 x 0.3 x 3.0 mm³.

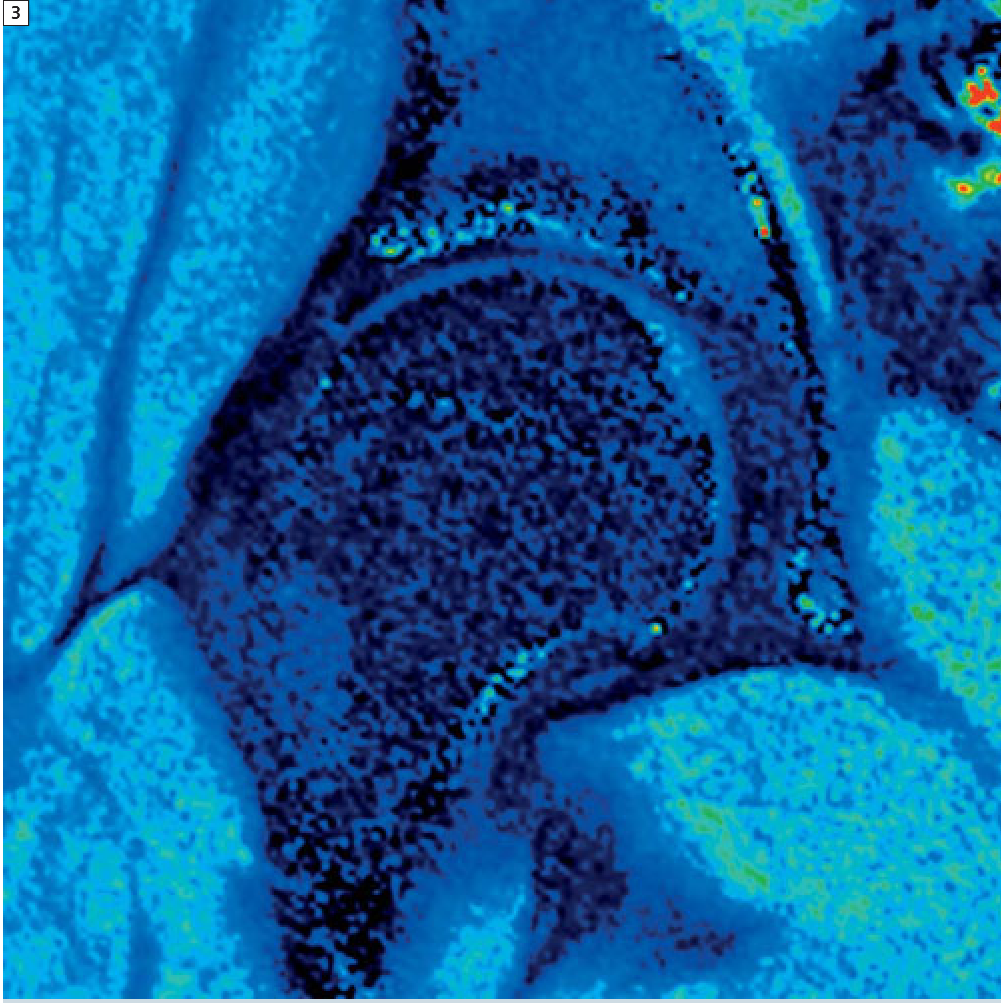
2 In this figure, the corresponding image to figure 1 of one of the two corresponding T1-weighted VIBE measurements is shown; this sequence is used for the dual flip angle fast T1 mapping. Resulting voxel size is 0.6 x 0.6 x 4.0 mm³.

the pre-existing articular cartilage damage in our clinical outcome after joint preserving procedures, we have incorporated the delayed Gadolinium Enhanced MRI of Cartilage (dGEMRIC) technique [2, 3] into our routine clinical imaging protocol. We have previously shown that dGEMRIC technique for the hip correlates with clinical symptoms [4] and is the best predictor of outcome after joint preservation surgery [5]. This technique takes advantage of the fact that in early OA, the negatively charged extracellular matrix is lost [6]. Using the dGEMRIC technique, the charge density is measured by the change in T1 relaxation times of the articular cartilage after penetration of gadopentetate-DTPA(2-) into the tissue. Intravenous injection of gadolinium allows the most rapid penetration of contrast agent into the articular cartilage due to penetration both from the synovial fluid as well as the subchondral bone. The patient needs to move the joint after injection and the dGEMRIC imaging needs to occur within a 30–100 minute time window after injection for a reliable biochemical assessment of the articular cartilage [7, 8].

Clinical imaging protocol

In our current clinical routine scan, we use a 1.5T Siemens MAGNETOM Avanto scanner with a surface coil for hip imaging. The patients are injected with Gadopentetate dimeglumine (Magnevist; Berlex Laboratories, Wayne, NJ). They are then asked to walk for 15 minutes. The imaging is started 30 min after contrast injection and the imaging protocol includes sequences for morphologic and biochemical imaging. The intra-venous gadolinium injection provides an indirect arthrogram and is much better tolerated by the patients than a direct injection arthography, which in many centers is the standard. Our imaging protocol consists of the following sequences:

3



3 The resulting T1 map for the dGEMRIC imaging is shown in this figure. This map is calculated Inline using *syngo* Mapit. The blue color code shows different T1-times (the darker blue the color, the shorter the T1-time). The cartilage is well delineated and structural changes can be easily obviated or visualized.

1) coronal and sagittal oblique Turbo Spin Echo (TSE) acquisition with fat saturation (Fig 1.) (TR 530 msec, TE 11 msec, FOV 160 mm, matrix 512 x 512, slice thickness 3 mm),
2) 3D isotropic TrueFISP acquisition with water excitation (TR 12.6 msec, TE 5.5 msec, flip angle 30, FOV 160 mm, matrix 256 x 256 x 256, 0.63 mm voxel size),
3) Dual flip angle fast T1 mapping using two VIBE acquisitions for dGEMRIC imaging (Fig 2.), (TR 20 msec, TE 4.8 msec, flip angle 4.8/26.9, FOV 160 mm, matrix 256 x 256, slice thickness 4 mm).

The total scan time for this protocol is under 30 minutes and the *syngo* MapIt software performs the Inline T1 map calculations for the dGEMRIC imaging obviating the need for post-processing of imaging data (Fig. 3). Additionally, the 3D isotropic TrueFISP imaging data set is reconstructed in a rotating imaging plane around the femoral neck axis for accurate femoral head-neck junction and articular cartilage and labral characterization.
In order to obtain an accurate and reliable dGEMRIC imaging, the need for the patient to move the joint and delay the imaging for the appropriate amount of time is critical since the imaging technique relies on penetration of the contrast agent into the articular cartilage. Additionally, it is the anionic form of gadolinium that provides specificity to the imaging technique, hence, care must be taken to use the appropriate contrast agent. The dual flip angle fast T1 mapping technique with Inline map calculation makes this technique practical by decreasing the imaging time to practical levels and eliminating the

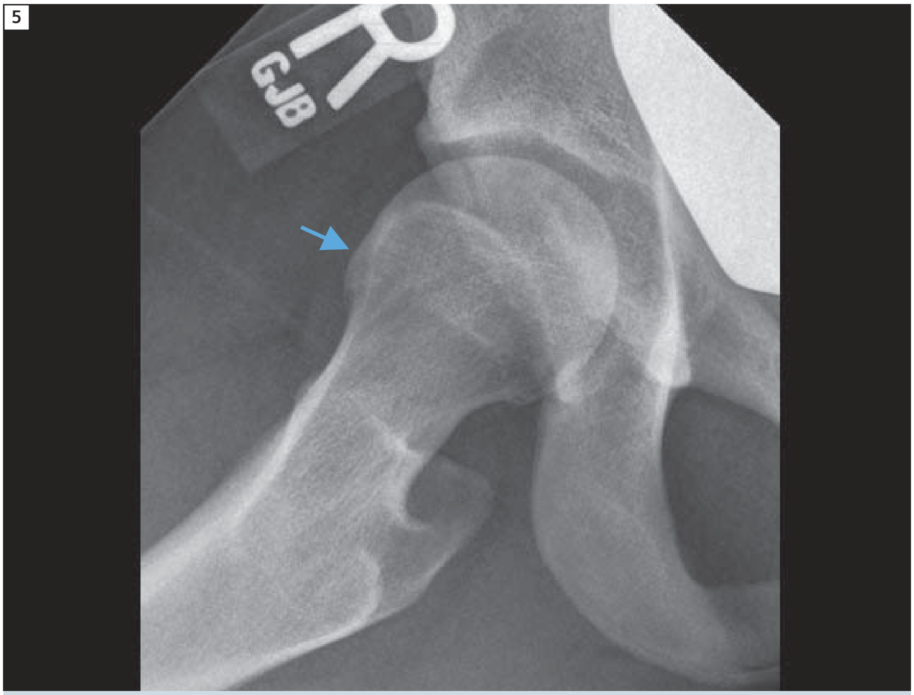
need for post-processing of the imaging data. The dual flip angle technique has been validated against the traditional inversion recovery technique. With this gradient echo based technique, it is important to center the hip in the middle of the imaging matrix since the T1 mapping data is inaccurate at the periphery of the imaging matrix. Additionally, the choice of flip angles are critical for this fast T1 mapping technique since the range of T1 in which this technique will be accurate is limited [9].

Clinical case example

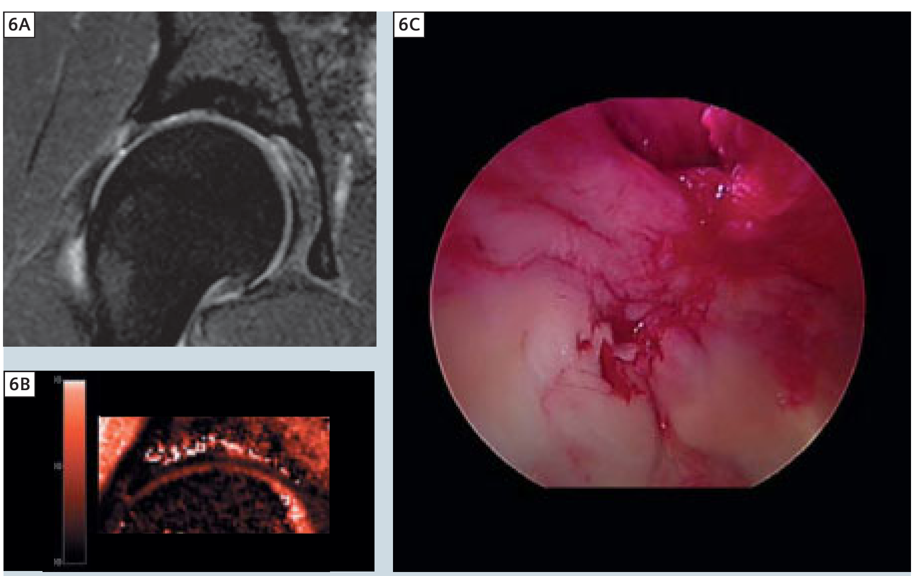
The utility of this technique is illustrated in this case of a 19-year-old college hockey player suffering severe right hip pain that initially limited her playing. Eventually, the pain increased to the point where even every day activity became limited. The plain radiographs show intact joint space with no obvious evidence of osteoarthritis (Fig. 4). The lateral radiograph shows the prominence in the anterior head-neck junction consistent with a Cam type femoroacetabular impingement (Fig. 5). The surgical treatment options range from a limited anterior open arthrotomy and osteochondroplasty to a full surgical dislocation with trimming of the damaged acetabular rim and femoral head-neck junction osteochondroplasty. Advanced imaging is critical in proper patient selection for each surgical technique as well as predicting the prognosis of this patient after surgery.
The standard morphologic imaging shows some heterogeneity in the acetabular articular cartilage (Fig. 6 A). The femoral head cartilage appeared intact and the labrum appeared intact. However, on the dGEMRIC scan, the entire acetabular cartilage showed markedly lower T1 values, demonstrating increased enhancement of the extracellular matrix by the gadopentetate-DTPA(2-), suggesting lower inherent negative charge in the matrix and hence significant articular cartilage damage in the acetabulum (Fig. 6 B). Based on this information, the patient was scheduled for an open surgical dislocation and osteoplasty rather than the more limited surgery. At time of surgery, the extent of articular cartilage damage in the acetabulum is verified (Fig. 6 C).
The addition of the dGEMRIC imaging technique to our clinical hip imaging protocol allows us to improve patient selection and therefore improve the ultimate outcome of our surgical procedure. It also allows us to avoid unnecessary surgery with improved staging of the articular cartilage damage at time of initial assessment. Additionally, the indirect arthrogram is much better tolerated by the patients than a direct injection arthography and the imaging technique is sufficiently fast and easy to use to allow the full complement of diagnostic imaging sequences to run within a 30 min scan time as part of a routine clinical imaging protocol.

4

4 Pelvic radiograph of a 19-year-old woman with right hip pain. Minimal radiograph evidence of osteoarthritis is present. Some asphericity of femoral head suggesting possible impingement.



5 Lateral radiograph of the right hip shows a prominence in the anterior head-neck junction which could lead to Cam type femoroacetabular impingement.



6A Coronal TSE image shows some focal signal change in the acetabular articular cartilage. 6B The corresponding section on the dGEMRIC scan shows extensive articular cartilage change in the acetabular side but the femoral head cartilage appears intact. The lower T1 values (dark red and black areas) on the dGEMRIC scan corresponds to more cartilage degeneration. 6C The intraoperative view shows intact labrum but deep fissuring of the acetabular articular cartilage.

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