Magnetic resonance imaging of hip joint cartilage and labrum

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Abstract

Hip joint instability and impingement are the most common biomechanical risk factors that put the hip joint at risk to develop premature osteoarthritis. Several surgical procedures like periacetabular osteotomy for hip dysplasia or hip arthroscopy or safe surgical hip dislocation for femoroacetabular impingement aim at restoring the hip anatomy. However, the success of joint preserving surgical procedures is limited by the amount of preexisting cartilage damage. Biochemically sensitive MRI techniques like delayed Gadolinium Enhanced MRI of Cartilage (dGEMRIC) might help to monitor the effect of surgical or nonsurgical procedures in the effort to halt or even reverse joint damage.

Introduction

Osteoarthritis (OA) of the hip joint is a major cause for disability and pain in the adult population of developed countries.[1] Instability and impingement or combinations of instability and impingement are the most important mechanical factors that put the hip joint at risk of developing early OA.[2] Childhood diseases like hip dysplasia (instability), Legg-Calve-Perthes disease (static impingement) or slipped capital femoral epiphysis (dynamic impingement) are major etiologic contributors to the development of early hip OA.[3] While 50 years ago it was assumed that 50% of hip OA was not attributable to anatomic deformities (idiopathic OA),[4] nowhere days some authors suspect that more than 90% of hip OA is due to instability or impingement.[2]

In order to diagnose and treat patients with FAI or hip dysplasia according to the disease severity, adequate knowledge of magnetic resonance imaging of the hip joint pathology is mandatory.

Hip joint anatomy

The hip joint is large, has to bear a lot of weight and its stability is provided by its rigid ball-and-socket or nut-configuration as well as the surrounding strong ligaments and muscles. The acetabular cartilage is horse-shoe-shaped with a central part without cartilage coverage that does not articulate with the femoral head (fossa acetabuli). Within the fossa, fatty tissue and the ligamentum teres are imaged on MRI. The femoral head is completely covered with hyaline cartilage except for the insertion of the ligamentum teres. The hip joint cartilage is thin in comparison to other joints with the maximum thickness ventrocranially at the acetabulum and ventrolaterally on the femoral head.

The joint capsule is strengthened by 3 ligaments: the iliofemoral ligament is the strongest ligament of the 3 and originates from between the anterior inferior iliac spine and the acetabular rim and inserts along the anterior portion of the intertrochanteric line and greater trochanter. It assists in the maintainance of an erect posture without much muscular activity. The pubofemoral ligament originates from the ramus superior ossis pubis and inserts anterolaterally in the joint capsule while the ischiofemoral ligament is dorsally, originating from the ischium and going horizontally inserting on the upper limit of the intertrochanteric line.[5]

With increasing interest in hip arthroscopy, the role of the ligamentum teres as a secondary contributor to hip stability[5] is under re-investigation: lesions of the ligamentum teres have gained attentiveness through hip arthroscopy and have been described in up to 15% of hip arthroscopy patients and as a common cause of hip pain in athletes.[6-9] The ligamentum teres (Figure 11H) arises from the transverse acetabular ligament and is attached to the periosteum by to fascicles along the ischial and pubic marcins of the acetabular notch.[6] The acetabular labrum is a sealing rim around the hip joint that consists of fibrocartilaginous collagen fibers attached to the acetabulum and contiguous with the transverse aectabular ligament. The functions of the labrum comprise an increase of the acetabular volume, dissipation of force across the hip, facilitation of synovial lubrication, compensation for minor joint incongruities and dissipation of contact forces encountered by the hip joint.[10-15] The capsular side of the labrum consists of dense connective tissue, whereas the articular side is composed of fibrocartilage.[16] Without intrinsic vasculature the blood supply is provided by the capsule and synovium.[16-19] Its nociceptive and proprioceptive function are still under investigation. Different types of corpuscles represent pressure receptors, receptors of deep sensation and temperature sensation while free nerve endings are pain receptors.[10,17,20] Other than the nociceptive and proprioceptive impairment, a torn labrum will cause a reduction in the described mechanical sealing support thus not anymore maintaining the synovial fluid for force distribution, smooth gliding surface, and nutrition and thus resulting in more cartilage damage.[21]

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Rule out other factors of hip pain

In contrast to other joints and due to its anatomic position the hip joint is not always easy to examine and pain around the hip joint might be due to other factors than labral or cartilage damage due to FAI or dysplasia.

Avulsion fractures, insufficiency fractures, osteoporotic or pathologic fractures and tumors around the hip joint have to be ruled out as cause for hip pain. Chronic inflammatory arthritis including rheumatoid arthritis might be accompanied with morning stiffness and other systemic manifestations of the disease. Lumbar radiculopathy and lumbar spinal stenosis might mimic hip pain. Intrapment of the lateral femoral cutaneous nerve might cause meralgia paresthetica with pain or numbness on the lateral aspect of the hip and thigh. Lose intraarticular bodies, gout or pseudogout, synovitis or acute bacterial arthritis have to be ruled out as reason for hip pain. Piriformis syndrome is referred to an iritation of the sciatic nerve by the piriformis muscle. Iliotibial band syndrome might radiate along the lateral thigh and cause an external snapping hip, in contrast to the internal snapping hip that is caused by the iliopsoas muscle. Sports hernia or athletic pubalgia are occult hernias caused by weakness or tear of the posterior inguinal wall without recognizable hernia, Gilmore's groin with tear in the external oblique aponeurosis, conjoined tendon and dehiscence between the conjoined tendon and the inguinal ligament as well as injury at the insertion of the rectus abdominis muscle, avulsion of the internal oblique muscle or tearing within the internal or external oblique aponeurosis or muscle (Figure 1).[22-24]

Hip abductors have been compared to the rotator cuff of the shoulder[25,26] and gluteus medius tendinous or muscular pathologies including fatty degeneration may be graded and treated according to rotator cuff pathologies.[27]

Other reasons for referred hip pain might be synovitis or mechanical blockade or the sacroiliac joint, osteitis pubis, muscle injuries and enthesiopathies of the adductors, iliopsoas or hamstrings. Chronic microtrauma and injury to the adductors might be caused by an externally rotating *cam-avoidance* gait pattern in cam-FAI-patients.[28,29] A *sports hip triad* has been described recently decribed, consisting of a labral tear, adductor strain and rectus strain.[30]

Bursae might be inflamed and swollen and might be mistaken for tumors or cysts. Bursae commonly affected by acute or chronic bursitis are the greater trochanteric bursa, the iliopectineal bursa (= ilioposas bursa) and the ischiogluteal bursa (Figure 2).

The iliopectineal bursa is the biggest bursa around the hip joint and might communicate with the hip joint in 15% of the people. That is why in MR-arthrograms contrast agent might extend into the iliopsoas (Figure 3).

Therapy of avascular necrosis (AVN) of the femoral head depends on the stage of the disease. MRI has reported sensitivities and specifities as high as 100% for the detection of ON (Figure 4).[31] Treatment strategies for AVN depend on the stage of the disease that might be classified by the Association Research Circulation Osseous (ARCO).[32-34] Since joint preserving procedures for advanced stages of AVN are limited, early diagnosis and effective treatment are necessary.[35,36] The vasoactive, stable prostacyclin analogue iloprost is approved for therapy of critical limb ischemia due to peripheral arteriosclerotic obliterative disease and diabetic angiopathy as well as an inhalative for patients with pulmonary arterial hypertension.[37] Our group and others use iloprost for the treatment of early stages of AVN.[38-41]

Labrum

The healthy labrum has a triangular shape with sharp margins and continous attachement to the acetabular rim and cartilage (chondrolabral junction).[42] The labrum is contiguous with the transverse aectabular ligament, which appears cuboid and marks the medial-inferior part of fossa acetabuli. A labral tear shows increased intra-substance signal with in labral detachment from the acetabular rim, synovial-fluid-intensity signal will undermine the labrum. Labral tears are typically located antero-superiorly. A degenerated labrum appears clumsy with intralabral signal alteration due to mucoid degeneration (Figure 5).

In order to achieve useful images, high MR resolution and contrast to noise ratio are required. Non-contrast MRI is used for the evaluation of bone, necroses, tumors, muscles and marrow space. It seems to be unreliable for detecting more subtle lesions. Mintz et al. found a sensitivity of 96%, a specificity of 33% and an overall accuracy of 94% for the detection of labral tears at 1.5T.[43] Sundberg *et al.* found comparable results for the detection of labral tears comparing 3-T non-arthrographic with 1.5-T arthrographic techniques.[44] With the studies available today, non-contrast MRI is not optimal in the evaluation of cartilage and labrum. In the future and with more sophisticated hardware and software as well as the availability of higher field strength machines, this may change. Direct Magnetic resonance arthrography (d-MRA) after the intra-articular injection of gadolinium-based contrast agent has emerged as the standard method for the evaluation of labrum and cartilage.[45-48] Approximately 10-20 mL of contrast agent is injected into the hip joint under fluoroscopic guidance, followed by MRI within approxi-

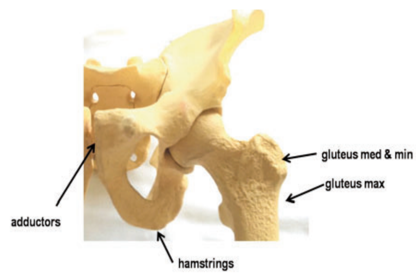


Figure 1. Common locations of tendinosis and sprain in the athlete.

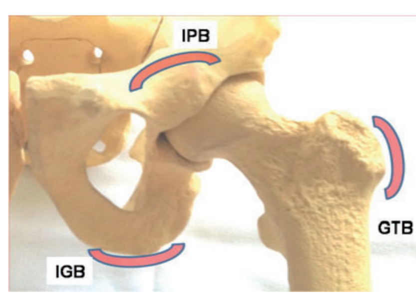


Figure 2. Bursae of clinical relevance.

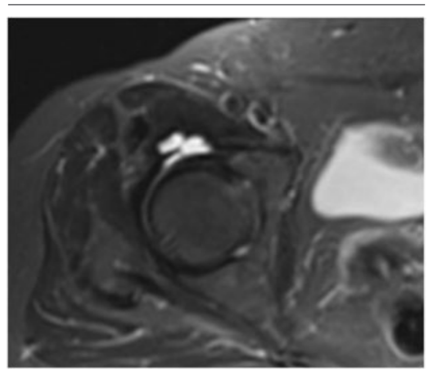


Figure 3. Bursitis and distension of a bursa iliopectinea.

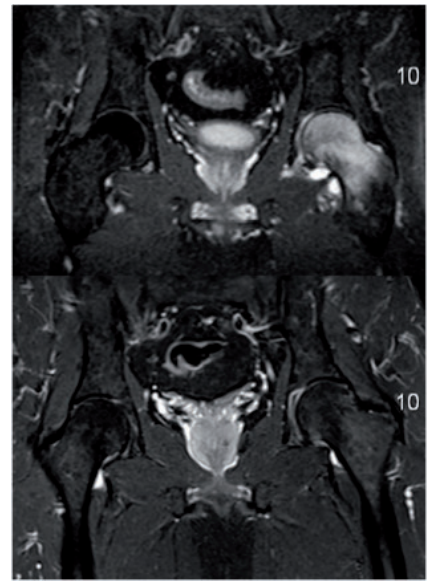


Figure 4. AVN ARCO I.

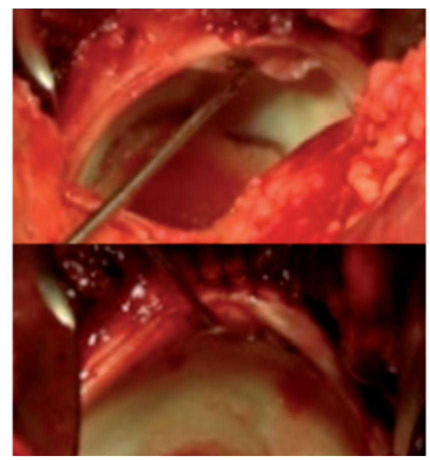


Figure 5. Torn Labrum, suture during surgical hip dislocation.

Figure 6. Intra articular contrast administration.

mately 30 minutes (Figure 6).[49] The intraarticular contrast agent increases the spatial resolution and causes a capsular distension with separation of capsule, labrum and osteochondral structures. The contrast agent can fill into labral and cartilage clefts. Compared to hip arthroscopy as gold standard, d-MRA is reported to have sensitivities of 63-100%, specificities of 44-100% and accuracy values of 65-96%.[50-55] For the detection of labral tears, the inter-observer reliability has been reported to be moderate.[50,56] With 2 dimensional in contrast to 3 dimensional MRI techniques, the assessment of thickness and orientation of the acetabular lesion was not optimal.[45,50] For indirect MRA (i-MRA) of the hip joint, gadolinium-containing contrast agent is administered intravenously, followed by a delay with or without physical activity. The contrast agent will distribute into the joint, enhancing synovial fluid and providing greater contrast as well as distension of the capsule, allowing for the interpretation of labrum and cartilage.[49,57-61] In one study comparing i-MRA and d-MRA, i-MRA showed a sensitivity of 88% and an accuracy of 90%.[62] Byrd *et al.* demonstrated that D-MRA was much more sensitive in the detection of various lesions, however, arthroscopy demonstrated that d-MRA was interpreted falsely positive twice as much compared to i-MRA (Figure 7).[63] One major advantage for the d-MRA is the possibility to perform a diagnostic infiltration of the hip joint at the same time as contrast agent administration: it has been shown that the reduction of pain after intra-articular administration of a local anesthetic is a 90% reliable indicator of intraarticular pathology.[63] However, the informational value of this probe-infiltration of the hip joint is diminished by the fact that with administration of 20 mL of contrast agent the joint capsule is distended, causing pain itself. Advantages of i-MRA versus d-MRA comprise: the lesser risk of vascular or nerve injury by the injection; the absence of radiation through fluoroscopy; the reduced resource and time intensity as well as reduced logistical effort.

Cartilage

Hip joint cartilage is thin and bony hip anatomy is complex with the shape of the head being more or less spherical. Cartilage lesion assessment is not as well established as labrum lesion assessment. Non-contrast techniques to describe cartilage changes revealed low diagnostic efficiency with sensitivities of less than 50%.[64] Mintz *et al.*[43] described a low reliability in classifying cartilage according to cartilage thickness and signal intensity changes according to the Outerbridge Score.[65] In a study of Schmid *et al.,* the sensitivity of cartilage grading was only 47%.[56] Overall the cartilage diagnosis in the hip joint is limited so far and no reliable staging and grading system has been established.[50,56,66,67] The articular cartilage can be graded with a modification of the classification system of Outerbridge (Table 1).[43]

Femoroacetabular Impingement

The concept of femoroacetabular impingement (FAI) as a major contributor to the development of premature hip OA has been recognized and accepted all over the world. Table 2 demonstrates the remarkable number of publications in PUBMED concerning *femoroacetabular impingement* within the past decade. The cam-lesion is the reduced head-neck offset and bashes against labrum and acetabular cartilage during flexion and internal rotation. This mechanism may cause cartilage delamination from the subchondral bone and labrum. This carpet phenomenon is located mostly in the anterosuperior region of the acetabulum.[68-70] as well as causing intraarticular cartilage damage. In pincer FAI, the acetabulum might be too deep globally or locally, causing an abutment of the femoral neck against the acetabulum so that the labrum might be damaged prior to cartilage damage.[71-75] Further causes for FAI are rotational anomalies with reduced femoral neck antetorsion and/or reduced acetabular retroversion[72,76] or a focal overcoverage after periacetabular osteotomy (PAO) (*Bernese Disease*).[77] In many cases patients show pincer and cam deformities (Figure 8). Untreated FAI can lead to premature osteoarthritis (OA)[69,83] and surgical intervention by open surgical dislocation of the hip, arthroscopy or combined approaches may be warranted. Surgical treatment is associated with positive medium- and long-term outcome. A comparison of the three therapy methods is difficult due to the different outcome measures employed. Studies directly comparing the approaches are warranted to distinguish more clearly between the different treatment options.[78] As in surgery for hip dysplasia, the outcome of surgery depends on the quantity of pre-existing OA with poor results in patients with advanced degenerative changes. Beck et al. described after favourable results after open or arthroscopic FAI-surgery in particular in the subgroup of patients without advanced OA.[69,83] Therefore in FAI-as well as in hip dysplasia patients it is of great importance to identify early stages of cartilage degeneration to be able to identify patients that will profit from osteo- and/or chondroplastic types of surgery.

Diagnosis of FAI

Diagnosis of FAI is based on clinical findings, standard x-rays (anteroposterior and lateral) and MRI. Plain radiographs are often inadequate in underrepresenting the extent of head-neck pathology.[79] Due to the importance of detecting the extent of the deformity as well as early cartilage and labral lesions, MRI is the standard tool for diagnosis of FAI.[46] Furthermore, it is becoming clear that standard coronal, axial and sagittal MR views are less reliable than radially reconstructed planes perpendicular to the acetabular labrum in detecting early degenerative pathologies of the hip.[46,80] For the assessment of the femoral head-neck morphology, radial reconstructions along the femoral neck axis are described[54,81,82] that improve the understanding of the FAI pathomechanism and correlate well with the prediction of an FAI and intra-operative findings.[83] These imaging techniques are increasingly

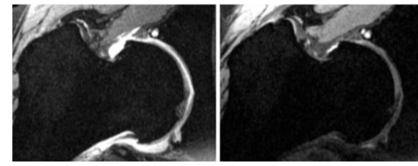


Figure 7. Comparison of i-MRA and d-MRA in one Patient with FAI, cartilage damage and torn labrum.

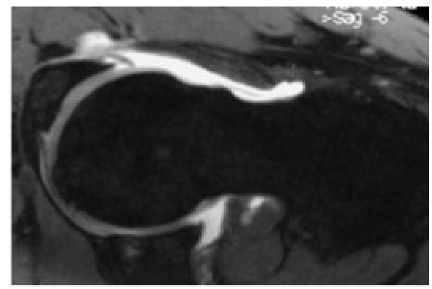
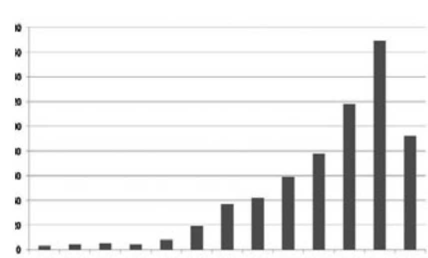


Figure 8. Radial image of a patient with mixed FAI demonstrating a deep socket and a bump deformity. Corresponding labral tear and paralabral cyst.

Table 1. Modified Outerbridge classification for cartilage damage.

	Grade	Macroscopy	MRI
	0	Normal cartilage	Normal cartilage
	1	Rough surface; chondral softening	Inhomogenous, high signal; surface intact
	2	Irregular surface defects; <50% of cartilage thickness	Superficial ulceration, fissuring, fibrillation; <50% of cartilage thickness
	3	Loss of >50% of cartilage thickness	ulceration, fissuring, fibrillation; > 50% of the depth of cartilage
	4	Cartilage loss	Full thickness chondral wear with exposure of subchondral bone

Table 2. Publications concerning FAI.



recognized as an important tool for morphologic assessment of FAI as well as improved techniques to detect early labral and chondral damage in the hip (Figure 9).[84]

Measurements in FAI

On MRI, different parameters defining FAI can be measured: alpha-angle, head-neck-offset, acetabular depth and acetabular version (Figure 10). Easiest to measure and most important is the alpha-angle of Nötzli[86] that can be measured as described by Pfirrman:[67] the angle is measured between an axis parallel to the femoral neck and passing through the narrowest portion of the femoral neck, and an axis passing through the point were the head contour passes into the metaphysis as shown in Figure 11K. An angle of more than 55 degrees is indicative of cam deformity. An interval of 30° among the radial reformats should be used to assess alpha angle. The acetabular coverage might be measured by assessing the acetabular depth within in axial reformation. The depth is expressed as distance between a line drawn among anterior and posterior acetabular horn and the center of the femoral head. The acetabular version can be measured on axial 2D T1 weighted images through the acetabular roof, when on the image superiorly where anterior- and posterior rim become apparent. However, acetabular version is better estimated on plain ap radiographs.

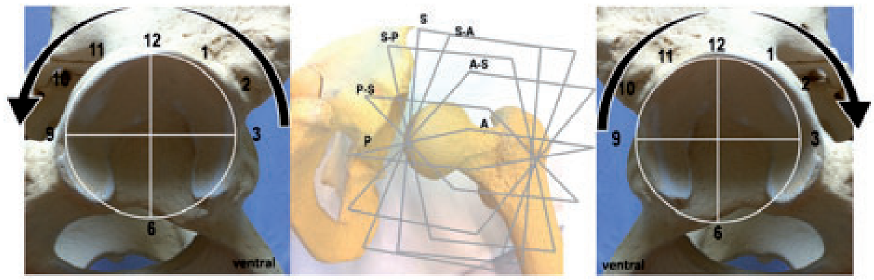


Figure 9. Radial sequences.

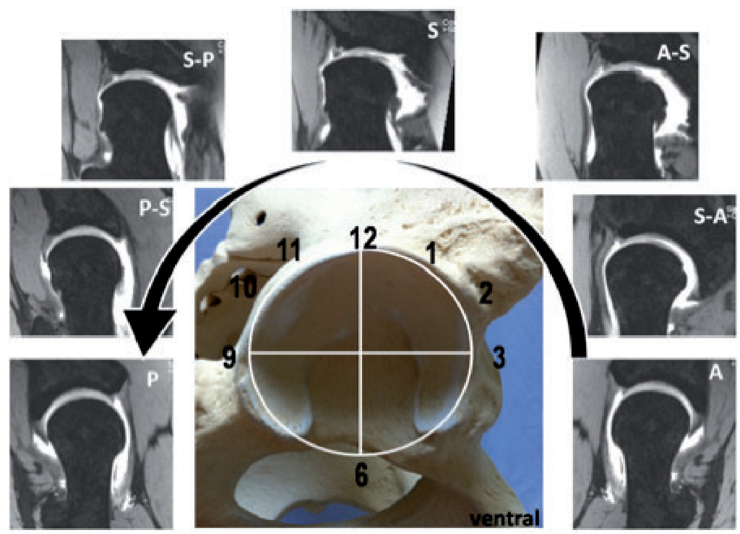


Figure 10. Radial images in a hip dysplasia patient.

Hip dysplasia

In contrast to the FAI, the labrum is typically thick and tears or dissociations are often further dorsolaterally. Chronic overloading of the labrum causes mukoid degeneration and cysts. In hip dysplasia, cartilage damage is more globally than in FAI,[87] although intra-operative findings show, that cartilage damage occurs predominantly in the antero-superior quadrant both in DDH and in FAI.[69,71,88] Figure 12 shows the hip joint of a 17 year old patient with symptomatic labral tear and hip dysplasia.

MRI appearance of normal and pathologic features

Labral shape can differ from small and sharp to thick and round or even absent. Increased signal within the labrum is found in symptomatic as well as asymptomatic patients. A poor histologic correlation is reported for these MRI-findings.[89] Figure 11A shows an intralabral cyst in a 24 years old asymptomatic women. Figure 11B shows a torn labrum in a symptomatic patient that profited from intra-articular lidocain-injection. Obvious perilabral cysts are shown in Figure 11E in a 28 years old woman with extensive hip dysplasia. Sublabral sulcus or recessus (Figure 11F) are reported to be present in about 25% of patients without pathological meaning[90,91] while other investigators found no evidence of a normal sublabral sulcus.[48,92] Perilabral recesses (Figure 11G) can mimic cysts or be mistaken for a labral tear. D-MRA helps appreciating the recess in contrast to i-MRA (Figure 7).[48,93] Figure 11D shows an os ad acetabuli in a symtpomatic FAI-patient. The os ad acetabuli is frequently assicoated with FAI and might be due to a nonunion of secondary acetabular ossification centers, ossifications of the labrum or incomplete healing of rim fractures.[94] Supra-acetabular fossae (Figure 11C) appear as additional cavity anterosuperiorly and can be mistaken for osteochondral defects or osteochondrosis dissecans.[95] Lesions of the ligamentum teres (Figure 11H) have gained attentiveness through hip arthroscopy and have been described in up to 15% of hip arthroscopy patients and as a common cause of hip pain in athletes. Plicae are embryologic remnants in synovial joints that are often symptomatic in the knee joint, whereas in the hip joint, reports are anecdotic. Fu *et al.*[96] describe 3 locations for plicae: labral, ligamentous and neck plicae. The pectinofoveal fold is a band that runs parallel to the inferior neck (Figure 11I) with an incidence of 95% in MRI and 99% in hip arthroscopy,[97] this structure should be regarded as normal and distinguished from pathologic and symptomatic plicae. Slipped capital femoral epiphysis (SCFE)[98,99] might cause cam impingement and early OA. Figure 11J shows the MRI of a 39-year old women with advanced OA with osteophytes and capital drop in the long term follow up after SCFE. The alpha angle is added to Figure 11K as mentioned above. Herniation pits (Figure 11L) are fibrocystic changes along the anterior head-neck-junction that are speculated to be second to FAI.[100,101]

Biochemical Imaging

Even high field MRI machines image fairly late events while minor changes in cartilage degeneration or regeneration cannot be monitored. Biochemical or molecular imaging of cartilage offers the perspective of closely watching into the cartilage structure. Thus, the real amount of cartilage damage can be visualized and the effect of surgical or non-surgical intervention may be observed. Different biochemical imaging methods are able to visualize cartilage quality in measuring collagen or glycosaminoglycan (GAG) content of cartilage. The imaging modalities can be

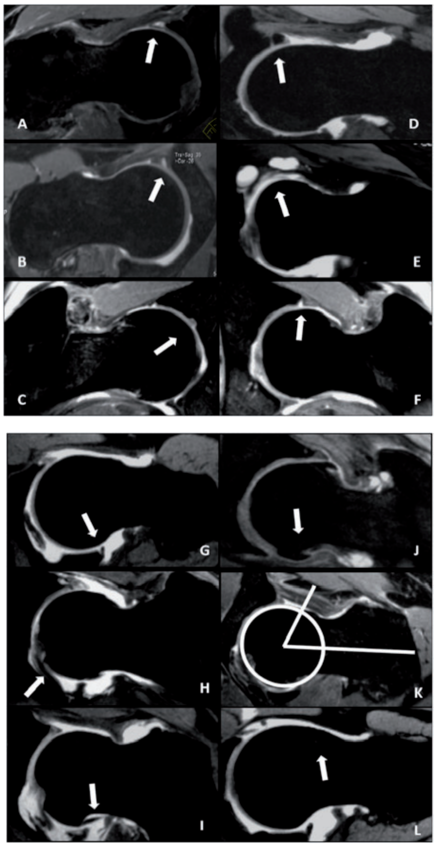


Figure 11. MRI appearance of normal and pathologic features.

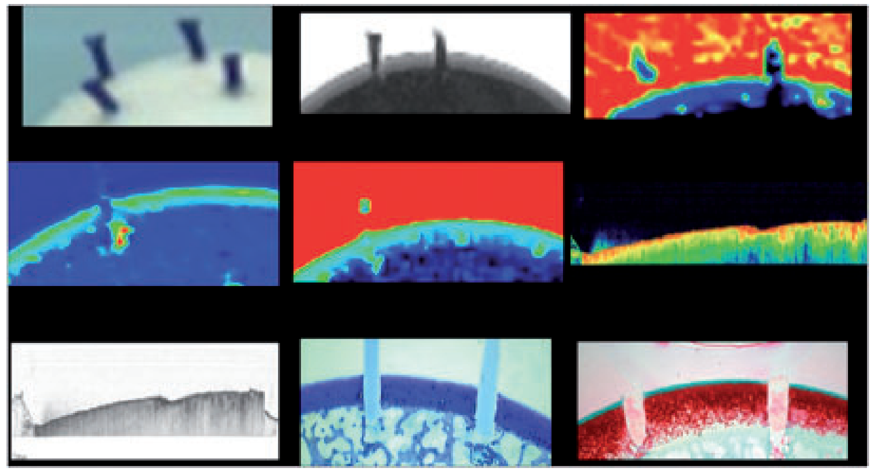


Figure 12. Pre-OP x-ray.

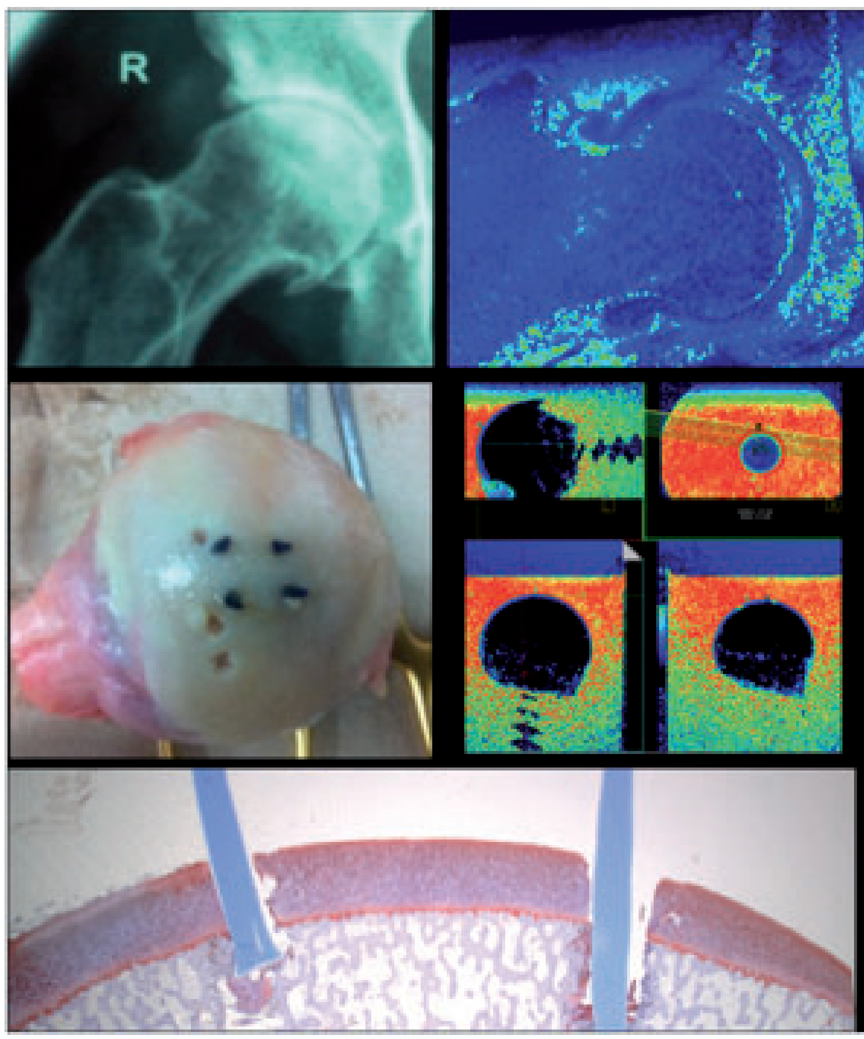


Figure 13. Histo and OCT.

conducted at regular MRI machines, using the contrast agent, that is also employed on a routine basis. Acquisition time is not much higher than standard morphological sequences. However, the post-processing of the images is still fairly sophisticated and time-consuming, preventing these new and promising techniques to become incorporated into clinical routine. GAGs are proteins of the extracellular cartilage matrix that make out more than 90% of the negative cartilage charge. GAG are lost early in the development of OA[102] and might be repleated in cartilage regeneration. Delayed Gadolinium Enhanced MRI of Cartilage (dGEMRIC) takes advantage of this fact: after intra-articular or intra-venous injection, the negatively charged contrast agent gadolinium-diethylene triamine pentaacetic acid (Gd-$DTPA^{2-}$) penetrates into the cartilage in a reciproce proportional manner to the content of GAG within the cartilage. The contrast agent within the cartilage causes a reduction of T1-time that can be measured in MRI. The dGEMRIC index or $T1_{Gd}$ represents the GAG content within cartilage and high $T1_{Gd}$ values are supposed to be found in healthy cartilage whereas low $T1_{Gd}$ values are found in degenerated cartilage, due to the higher amount of Gd-$DTPA^{2-}$ within the cartilage. After i.a. or i.v. administration of contrast agent, a delay of 30 to 60 Minutes is warranted before the MRI is performed.[103] T1 relaxation times that are investigated are: T10 (i.e. T1 prior to contrast administration), $T1_{Gd}$ (post-contrast T1) and $\Delta R1$ that defines the difference in relaxation rate ($R1 = 1/T1$) between $T1_0$ and $T1_{Gd}$ measurements ($1/T1_{Gd}$-$1/T1_0$). Some authors found out that ΔR1 is a more precise parameter to reflect the Gd-DTPA^{2-} concentration within cartilage as.[104-106] Bittersohl *et al.* evaluated $T1_{Gd}$ and ΔR1 in two different radiographic grades of hip osteoarthritis in symptomatic FAI patients.[107] Asymptomatic young-adult volunteers served as control. A high correlation between T1Gd and ΔR1 in all study groups could be observed. Based on these results, we conclude that $T1_{Gd}$ assessment is sufficient and a further pre-contrast imaging is not necessary. However, some circumstances require the calculation of ΔR1 for accurate GAG evaluation including follow-up of cartilage repair therapy where T10 values may differ especially in the early postoperative stages post-surgery.[105,106,108] Several clinical studies have been conducted so far to evaluate hip joint cartilage using dGEMRIC: in his classic report, Kim et al. report the diagnostic potential of dGEMRIC for assessment of early OA in patients with hip dysplasia.[59] Tiderius *et al.* evaluated the time course of T1 values after Gd-DTPA2- injection with hip dysplasia and early signs of OA.[109] The same group investigated 47 patients undergoing a Bernese periacetabular osteotomy (PAO) for the treatment of hip dysplasia.[110] Multivariate analysis identified the dGEMRIC index as the most important predictor of failure of the osteotomy. Still the same group retrospectively analyzed 37 symptomatic hips with FAI[60] and suggested that dGEMRIC may be a useful technique for diagnosis and staging of early osteoarthritis in hips with impingement. Pre-Arthritic deformities after SCFE and Legg-Calve-Perthes disease were evaluated using dGEMRIC.[111-115] GEMRIC may depict the complex damage pattern of hip joint cartilage spatially and qualitatively better than other radiographic methods. The limitation of these studies using 2-D sequences was that only coronal T1 maps could be obtained. However radial evaluation around the hip joint, which is standard in morphologically MRI or MRA, is essential for the detection of cartilage pathologies for.[46] Recently, fast T1 assessment using dual flip angle (FA) gradient echo (GRE) has been validated and was used in-vivo enabling faster imaging times and three-dimensional (3D) dGEMRIC.[108,116] This technique utilizes inline T1 measurement and allows for faster imaging. Bittersohl *et al.* proved this technique to be a reliable instrument in the assessment of asymptomatic hip joint cartilage.[117] In a pilot study Bittersohl et al. proved the feasibility of cartilage assessment in symptomatic FAI patients using intra-articular delayed Gadolinium Enhanced MRI of Cartilage (ia-dGEMRIC).[118] In another study Bittersohl *et al.*[119] found that mapping with both iv-dGEMRIC and ia-dGEMRIC demonstrated obvious differences between various grades of cartilage degeneration. In ongoing studies we evaluate sequences histologically: in patients that are scheduled for a total hip endoprothesis, an in vivo and postoperatively *in vitro* scan of the hip joint cartilage is performed. Both scans can be combined and evaluated histologically. Different sequences are then subject to further immunhistochemical analyses as well as optical coherence tomography. (Figures 12 and 13).

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