Femoral cartilage damage occurs at the zone of femoral head necrosis and can be accurately detected on traction MR arthrography of the hip in patients undergoing joint preserving hip surgery

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ABSTRACT

The primary purpose was to answer the following question: What is the location and pattern of necrosis and associated chondrolabral lesions and can they be accurately detected on traction MR arthrography compared with intra-operative findings in patients undergoing hip preservation surgery for femoral head necrosis (FHN)?

Retrospective, diagnostic case series on 23 patients (23 hips; mean age 29 ± 6 years) with diagnosis of FHN undergoing open/arthroscopic joint preserving surgery for FHN and pre-operative traction MR arthrography of the hip. A MR-compatible device for weight-adapted application of leg traction (15–23 kg) was used and coronal, sagittal and radial images were acquired. Location and pattern of necrosis and chondrolabral lesions was assessed by two readers and compared with intra-operative findings to calculate diagnostic accuracy of traction MR arthrography. On MRI all 23 (100%) hips showed central FHN, most frequently antero-superiorly (22/23, 96%) where a high prevalence of femoral cartilage damage was detected (18/23, 78%), with delamination being the most common (16/23, 70%) damage pattern. Intra-operative inspection showed central femoral head cartilage damage most frequently located antero-superiorly (18/23, 78%) with femoral cartilage delamination being most common (14/23, 61%). Traction MR arthrography enabled detection of femoral cartilage damage with a sensitivity/specificity of 95%/75% for reader 1 and 89%/75% for reader 2. To conclude, femoral cartilage damage occurs at the zone of necrosis and can be accurately detected using traction MR arthrography of the hip which may be helpful for surgical decision making in young patients with FHN.

INTRODUCTION

Femoral head necrosis (FHN) is a major cause of osteoarthritis of the hip joint [1]. In young patients, efforts are made to halt the course of osteoarthritis. Two distinct surgical principles have been applied traditionally to treat FHN. Core decompression [2, 3] and vascularized bone grafting [3, 4] aim to restore femoral head blood supply. Rotational [5, 6] or angular [7] femoral osteotomies are performed to position healthy bone into the main weight-bearing areas to prevent collapse and allow healing of the necrotic area. Historically these procedures have been performed from an extra-articular approach. More recently, open [8–14] and arthroscopic [15–17] procedures for surgical treatment of FHN have been described which offer direct access to the joint for bone grafting and chondral repair [18].
To date, the optimal surgical treatment for FHN remains controversial [1]. This may be related to the fact that surgical planning often relies on imaging studies which allow staging of the disease but do not provide further information on location and extent of intra-articular damage [19]. More specifically the use of standard imaging MRI planes does not enable an exact localization of necrosis [19]. In contrast radial images which are oriented perpendicular to the femoral neck could potentially allow an accurate anatomic allocation of FHN, comparable to imaging of the cam deformity [20]. Currently, a detailed pre-operative image analysis of intra-articular damage in FHN is lacking [19], despite its detrimental effect on outcome of joint preserving surgery for FHN [21]. Such information could be valuable for planning of chondral repair surgery [18]. MRI of the hip, even after intra-articular contrast injection often fails to detect hip cartilage damage [22, 23]. Typically, the tight coaptation of the hip prevents contrast accumulation which makes differentiation of cartilage layers difficult [22]. Recently application of leg traction during MR arthrography of the hip was introduced to overcome this problem and has shown promising first results in detection of intra-articular lesions in FAI [24–26]. Therefore, it was hypothesized that traction MR arthrography with radial imaging could be useful in the pre-operative characterization of FHN and associated chondral lesions.

The primary purpose was to answer the following question: What is the location and pattern of necrosis and associated chondral lesions and can they be accurately detected on traction MR arthrography compared with intra-operative findings in patients undergoing hip preservation surgery for FHN?

**MATERIALS AND METHODS**

**Patients**

After IRB-approval a retrospective, diagnostic study on patients with FHN diagnosed was performed between January 2016 and June 2019 at a tertiary hip preservation centre. Pre-operative diagnosis of FHN was based on the presence of a geographical low signal band on MRI according to the revised Association Research Circulation Osseous (ARCO) [27]. The institutional database was searched for patients undergoing open or arthroscopic reconstructive hip surgery for treatment of FHN with complete intra-articular inspection. Out of 27 patients (27 hips), 23 patients (23 hips) had pre-operative traction MR arthrography of the hip according to the institutional routine protocol and were included in the study. Mean age was 29 ± 6 years (11 men, 45%; Table I). Most frequently FNH occurred idiopathic (14/23, 61%). The majority of hips (16/23; 70%) were diagnosed with advanced ARCO Stage III [27]. Nine hips (9/23, 39%) had Tönnis Grade 0, and 14 hips (14/23, 61%) had Tönnis Grade 1 of radiographic osteoarthritis [28] (Table I).

**Surgical treatment**

Twenty-three patients (23 hips) underwent joint preserving surgery, which was performed by three experienced hip surgeons (Table I). In six hips (6/23, 26%) hip arthroscopy was performed including core decompression. In 17 hips (17/23, 74%), surgical hip dislocation was performed with direct treatment of the necrotic lesion at the femoral head performed in 14 hips (14/23, 61%). Most commonly curettage of the necrotic bone was performed, followed by impaction bone grafting and suturing of the femoral head cartilage (7/23, 30%) (Fig. 1) or autologous matrix-assisted chondrogenesis (3/23, 13%) [10]. Labral refixation was performed in nine hips (9/23, 39%) and subchondral drilling of the acetabulum was performed in five hips.
Table I. Demographic and radiographic characteristics

| Characteristics                                      | Patients (hips) | 23 (23) |
|------------------------------------------------------|----------------|---------|
| Age (years)                                          | 29 ± 6         |         |
| Men (%)                                               | 11 (45)        |         |
| Body mass index (kg/m²)                              | 25 ± 3         |         |
| Tönnis grade of osteoarthritis, hips (%)             | Grade 0: 9 (39) |         |
|                                                      | Grade 1: 14 (61) |       |
| LCE angle (°)                                        | 28 ± 9         |         |
| Hip dysplasia (LCE < 25°), hips (%)                  | 7 (30)         |         |
| Deep hip (LCE > 39°), hips (%)                       | 1 (4)          |         |
| Retroversion (positive COS, PWS and ISS signs), hips (%) | 3 (12)     |         |
| Alpha angle (°)                                      | 74 ± 12        |         |
| Cam deformity (α > 60°), hips (%)                    | 21 (91)        |         |
| Aetiology, hips (%)                                  | 14 (61) idiopathic |       |
|                                                      | 6 (26) systemic/toxic |    |
|                                                      | 3 (13) post-traumatic |   |
| 2019 revised ARCO criteria (0–IV), hips (%)          | I (normal X-ray, MRI abnormal): 2 (9) | |
|                                                      | II (X-ray abnormal, MRI abnormal): 5 (22) | |
|                                                      | IIIA (subchondral fracture, depression ≤ 2 mm): 8 (35) | |
|                                                      | IIIB (subchondral fracture, depression > 2 mm): 8 (35) | |
| Previous surgery, hips (%)                           | 2 (9) core decompression |   |
| Surgical approaches, hips (%)                        | 8 (35) surgical hip dislocation |   |
|                                                      | 6 (26) surgical hip dislocation, femoral osteotomy |   |
|                                                      | 6 (26) hip arthroscopy, core decompression | |
|                                                      | 3 (13) surgical hip dislocation, periacetabular osteotomy | |
| Femoral osteochondroplasty, hips (%)                 | 21 (91)        |         |
| Chondrolabral repair, hips (%)                       | 7 (30) curettage of necrosis, bone grafting and cartilage suture | |
|                                                      | 3 (13) curettage of necrosis, bone grafting, AMIC |   |
|                                                      | 3 (13) subchondral drilling femoral head |       |
|                                                      | 1 (4) curettage of necrosis and osteochondral autograft |   |
|                                                      | 5 (22) subchondral drilling acetabulum |       |
|                                                      | 9 (39) labrum refixation |       |

Values are expressed as mean ± SD with range in parentheses. COS, cross-over sign; PWS, posterior-wall sign; ISS, ischial-spine sign; AMIC, autologous matrix-assisted chondrogenesis; ARCO, association research circulation osseous; LCE, lateral center edge angle.
Weight-bearing of the necrotic area was reduced with a concomitant femoral osteotomy in four hips [10]: three hips (3/23, 13%) inter-trochanteric varus-derotation osteotomies, one hip (1/23, 4%) posterior rotational femoral neck osteotomy. In two hips (8%), subtrochanteric derotation osteotomies were performed for correction of excessively high femoral version [33, 34]. Femoral osteochondroplasty was performed in 21 hips (21/23, 91%). In all patients, presence, location and damage pattern of intra-articular lesions was recorded intra-operatively according to the grading of Beck et al. [35]. For comparison with imaging findings surgical records were reviewed by an orthopaedic surgeon and femoroacetabular cartilage was graded: intact/delamination/thinning/defect. The acetabular labrum was graded as intact/chondrolabral separation/complex tear.

Image analysis
Radiographs were assessed by one senior orthopaedic surgeon for staging of FHN according to the 2019 revised ARCO grading [27]. The lateral-centre edge angle was measured, presence of acetabular retroversion (cross-over sign, posterior-wall sign and ischial-spine sign) was assessed [36] and the Tönnis grade of osteoarthritis [28] was evaluated. MRI analysis was performed independently from each other, blinded to the initial report and the surgical report by a radiology resident and a senior radiologist (7 and 19 years of experience).

Radial images were used to assess the location of FHN at each half-hour position of the clock-face. Image criterion for FHN was defined as the presence of a geographical, hypointense line in the femoral head and was recorded dichotomously (yes/no) [19]. On each radial image a line perpendicular to the femoral neck axis was drawn for definition of central (medial to the perpendicular line) or peripheral (lateral to the perpendicular line) FHN (Fig. 2). Anatomic allocation of FNH was performed using a previously described approach (see below) [20].

Coronal-, sagittal- and radial- traction MR images were used to assess chondrolabral lesions. Definite anatomic allocation of lesions to the corresponding clock-face positions was performed on the 12 radial images using a previously validated technique [20, 32]: Each image represents a ‘half-hour’ position and can be allocated according anatomic landmarks. For necrosis and femoral cartilage damage the greater trochanter served as landmark for the femoral 12 o’clock position. For acetabular cartilage and labrum lesions the acetabular teardrop served as landmark for the acetabular 6 o’clock position. Accordingly, the acetabulum and femur were divided into four quadrants: 12–2:30 o’clock = antero-superior; 3–5:30 o’clock = antero-
inferior; 6–8:30 o’clock = postero-inferior and 9–11:30 o’clock = postero-superior.

Femoral and acetabular cartilage lesions were graded using previously described classifications: delamination (subchondral contrast accumulation), thinning (partial-thickness loss of cartilage; Fig. 3) [24, 37]. Femoral cartilage lesions were further divided into peripheral and centrally located lesions. Labrum lesions were graded as chondrolabral separation (contrast extending into the labral base) or complex tear (contrast extension into the labral base and within the labral substance) [24, 37].

Statistical analysis
Descriptive statistics including mean and SD were calculated. Inter-observer reproducibility and intra-observer reliability were assessed using Cohen’s kappa: < 0 poor agreement; 0.0–0.2, slight agreement; 0.21–0.4 fair agreement; 0.41–0.6, moderate agreement; 0.61–0.8, substantial agreement; 0.81–1, almost perfect agreement [38]. Sensitivity, specificity, accuracy, positive predictive value and negative predictive value of traction MR arthrography for detecting intra-articular lesions was calculated. SPSS version 25.0 (IBM, Armonk, New York, USA) was used for statistical analysis.

RESULTS
On MRI all 23 (100%) hips showed central FHN, which was most frequently located in the antero-superior (22/23, 96%) quadrant. Peripheral FHN was present in 8/23 (35%) hips, most frequently located in the antero-superior and -inferior quadrants (each 3/34, 13%; Fig. 4).

On traction MR arthrography most hips (19/23, 83%) demonstrated central femoral cartilage damage, most frequently located antero-superiorly (18/23, 78%). Femoral cartilage delamination was the most commonly (16/23, 70%) observed damage pattern (Fig. 4). Corresponding to that, intra-operative inspection showed central femoral head cartilage damage in the majority of the hips (19/23, 83%) most frequently located antero-superiorly (18/23, 78%), with femoral cartilage delamination being most common (14/23, 61%; Fig. 4). Traction MR arthrography enabled detection of femoral cartilage damage with a sensitivity/specificity of 95%/75% for Reader 1 and 89%/75% for Reader 2 (Table II; Figs 1 and 5). MRI grading of femoral cartilage lesions was consistent with surgical grading in 70% (16/23) of the cases for reader 1 ($\kappa = 0.427$, $P = 0.002$) and in 61% (14/23) of the cases for reader 2 ($\kappa = 0.403$, $P = 0.001$; Table III).

On MRI and at surgical inspection acetabular cartilage damage was present in 83% (19/23) and 87% (20/23) of the hips and was located most frequently antero-superiorly for both MRI (83%, 19/23) and at surgery (87%, 20/23), respectively (Fig. 6). Among the observed lesions acetabular cartilage delamination was most commonly observed on MRI (13/23, 57%) and intra-operatively (11/23, 48%; Fig. 6). Traction MR arthrography enabled detection of acetabular cartilage damage with a sensitivity/specificity of 90%/67% for reader 1 and 95%/33% for Reader 2 (Tables II and III). On MRI and at surgical inspection labrum lesions were present in 87% (20/23) of hips and
91% (21/23) of hips, with 87% (20/23) and 91% (21/23) being located antero-superiorly, respectively. Most commonly the lesions were consistent with labro-chondral separation (MRI: 10/23, 43%; surgery: 13/23, 57%; Fig. 7). Traction MR arthrography enabled detection of labrum damage with a sensitivity/specificity of 95%/100% for Reader 1 and 100%/100% for Reader 2 (Tables II and III). Substantial agreement ($\kappa = 0.747, P < 0.001$) between the two observers was observed for detection of FHN. Inter-observer agreement was moderate for grading of femoral- ($\kappa = 0.588, P < 0.001$) and acetabular cartilage lesions ($\kappa = 0.417, P < 0.001$), and substantial for grading of labrum lesions ($\kappa = 0.633, P < 0.001$; Table II).

**DISCUSSION**

Although FHN is a well-known pre-arthritis condition and many surgical treatment concepts have been proposed, a concise pre-operative description of location and pattern of necrosis and associated chondrolabral damage is currently lacking [1]. It could be shown that damage to femoral head cartilage is located at the zone of FHN most commonly affecting the central part of the antero-superior
femoral head. Traction MR arthrography was highly accurate in detecting chondrolabral lesions and allowed grading of chondrolabral lesions with moderate to substantial agreement between imaging and surgical findings.

Despite the fact that location of necrosis affects outcome of core decompression, femoral osteotomies and vascularized fibular grafting for treatment of FHN a detailed analysis of location of FHN is currently lacking [1]. Location of necrosis has been commonly described on coronal and sagittal MR images [39]. However due to their orientation, imaging planes which are not oriented perpendicular to the femoral neck preclude an accurate anatomic allocation [37]. Recently, the use of radial MRI has been proposed for planning the correction angle in rotational femoral osteotomy based on the location and extent of FHN relative to the remaining healthy bone [40]. By using radial MRI, a detailed topographical description of necrosis could be provided with good inter-observer agreement between two readers and identified the central antero-superior (96% of hips) quadrant as predominant location of FHN (Fig. 4). Since radial imaging is widely used as gold-standard for visualization of the cam deformity, implementation of radial images into a routine MR protocol for FHN may be straightforward [41].

Table II. Diagnostic performance of traction MR arthrography in detection of chondrolabral lesions compared with surgery

| Parameter                  | Femoral cartilage | Acetabular cartilage | Labrum |
|----------------------------|-------------------|----------------------|--------|
| No. of true-positives,     | 18                | 18                   | 20     |
| (no. of hips)              | 17                | 19                   | 21     |
| No. of false-negatives,    | 1                 | 2                    | 1      |
| (no. of hips)              | 2                 | 1                    | 0      |
| No. of true-negatives,     | 3                 | 3                    | 2      |
| (no. of hips)              | 3                 | 1                    | 2      |
| No. of false-positives,    | 1                 | 1                    | 0      |
| (no. of hips)              | 1                 | 2                    | 0      |
| Sensitivity (%)            | 95 (74–100)       | 90 (68–99)           | 95 (75–100) |
| Specificity (%)            | 75 (19–99)        | 67 (9–99)            | 33 (1–91) |
| Positive predictive value  | 95 (77–99)        | 95 (78–99)           | 90 (81–96) |
| Negative predictive value  | 75 (29–96)        | 50 (18–82)           | 67 (23–93) |
| Accuracy (%)               | 91 (72–99)        | 87 (66–97)           | 96 (78–100) |
| Inter-observer agreement   | 0.588             | 0.417                | 0.633  |

Numbers in parentheses are 95% CIs.
P values ≤ 0.001.
only 32% of the cases compared with arthroscopic staging of joint damage when a femoral osteotomy was planned. To improve the otherwise poor visualization of the femoral head cartilage in FHN, application of traction during MRI of the hip has been first described more than 20 years ago using non-contrast MRI combined with 10–15 kg of traction in five patients undergoing hip arthroplasty [44].

A modified traction technique for MR arthrography was used in this study which is similar to the arthroscopic approach to gain access to the central joint compartment. This includes intra-articular contrast injection to break the suction seal, a weight-adapted traction force and a supporting plate for the contralateral leg to stabilize the pelvis [30, 45]. In contrast to previous reports this enabled us to detect femoral and acetabular cartilage damage in FHN with high sensitivity ranging from 89–95% to 90–95%, respectively (Figs 1 and 5). Thus, instead of performing surgery for diagnostic purposes cartilage damage may be assessed with traction MR arthrography to identify those patients who may still benefit from joint preserving surgery for FHN or should be rather considered for hip replacement thereby reducing costs and number of subsequent surgeries. Additionally, a more detailed assessment of pre-operative cartilage damage may be helpful to determine cases in which a femoral cartilage repair may be beneficial. This is important as femoral cartilage repair usually requires an open surgical approach to the hip.

Using MRI with intra-operative comparison femoral cartilage delamination was the predominant pattern of damage to the central, antero-superior femoral head where FHN was most frequently detected (Figs 1, 2 and 5). This supports the concept of cartilage debonding occurring secondary to underlying subchondral fractures [43, 44]. The imaging findings observed in this study may have potential implications for planning of femoral cartilage repair surgery in FHN for which promising short-term outcome have been reported even in cases with large necrotic lesions [10, 11, 13]. Delaminated but otherwise intact femoral cartilage may be treated with curettage of necrosis, bone grafting and re-suturing of the cartilage flap (so called ‘trapdoor procedure’; Fig. 1) [10, 12], full-thickness defects may be treated with osteochondral grafts [13] or autologous matrix-induced chondrogenesis (Fig. 5) [11].

Furthermore, we could confirm findings of previous studies reporting a high prevalence of acetabular cartilage- and labrum lesions [8, 43, 46]. Interestingly, these lesions were predominantly present in the antero-superior quadrant and most frequently acetabular cartilage delamination and chondrolabral separation were observed (Figs 6 and 7). This location and damage pattern resemble the characteristic findings of cam-type FAI [35]. Thus, it has been suggested that these lesions are caused by an inclusion, cam-type mechanism subsequent to flattening of the femoral neck-junction in FHN [8]. Indeed, the majority of
Table III. Grading of chondrolabral lesions: traction MR arthrography versus hip surgery

| MRI: femoral cartilage (Reader 1/2) | Surgery: femoral cartilage | Total |
|-----------------------------------|-----------------------------|-------|
|                                    | Intact                      | Delamination | Thinning | Defect |       |
| Intact                            | 3/3                         | 1/2         | 0/0      | 0/0    | 4/5   |
| Delamination                      | 0/0                         | 13/9        | 2/0      | 1/1    | 16/10 |
| Thinning                          | 1/1                         | 0/2         | 0/2      | 1/1    | 2/6   |
| Defect                            | 0/0                         | 0/1         | 1/1      | 0/0    | 1/2   |
| Total                             | 4                           | 14          | 3        | 2      | 23    |

Concordant grading*—Reader 1: 16 (70%) $\kappa = 0.427$ and Reader 2: 14 (61%) $\kappa = 0.403$

| MRI: acetabular cartilage (reader 1/2) | Surgery: acetabular cartilage |       |
|---------------------------------------|-------------------------------|-------|
| Intact                                | 2/1                           | 1/1   | 1/0 | 0/0 | 4/2 |
| Delamination                          | 1/1                           | 9/8   | 2/0 | 1/1 | 13/10 |
| Thinning                              | 0/1                           | 0/0   | 3/6 | 1/0 | 4/7 |
| Defect                                | 0/0                           | 1/2   | 0/0 | 1/2 | 2/4 |
| Total                                 | 3                             | 11    | 6   | 3   | 23   |

Concordant grading*—Reader 1: 15 (65%) $\kappa = 0.465$ and Reader 2: 17 (74%) $\kappa = 0.616$

| MRI: labrum (reader 1/2) | Intact | Chondrolabral separation | Complex tear |       |
|--------------------------|--------|--------------------------|--------------|-------|
| Intact                   | 2/2    | 1/0                      | 0/0          | 3/2   |
| Chondrolabral separation | 0/0    | 9/8                      | 1/2          | 10/10 |
| Complex tear             | 0/0    | 3/5                      | 7/6          | 10/11 |
| Total                    | 2      | 13                       | 8            | 23    |

Concordant grading*—Reader 1: 18 (78%) $\kappa = 0.633$ and Reader 2: 16 (70%) $\kappa = 0.476$

*P values ≤ 0.002.

Patients presented with a cam deformity and a concomitant femoral osteochondroplasty was performed in 91% of the cases in this study. However, based on this observation alone it is not possible to draw any definite conclusions and further studies are needed to determine the aetiology of cam deformities and their significance in patients with FHN.

This study has a number of limitations. First, a relatively small group of patients with FHN was included which reflects the rare nature of the disease in young patients. However, according to the performed literature review this study includes the largest group of patients with FHN undergoing joint preserving surgery including comparison with pre-operative traction MR arthrography of the hip.
Second, the imaging protocol did not allow a direct comparison with standard MR arthrography obtained without traction as this was not feasible in a busy clinical setup. Future studies are needed to assess whether there is a benefit in diagnostic accuracy when applying traction to the hip during MRI compared with standard MRI techniques. Third, no clinical follow-up is presented since this was beyond the scope of this study. Thus, no comments regarding the surgical outcome and the predictive value of these imaging findings can be made.

To conclude, femoral cartilage damage occurs at the zone of FHN and can be accurately detected using traction MR arthrography of the hip. Based on these findings, pre-operative traction MR arthrography may have potential to better inform surgeons as they contemplate whether to perform total hip arthroplasty or joint preserving treatment with/without osteochondral repair in young patients with FHN.

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**CONFLICT OF INTEREST STATEMENT**

None declared.

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