Current Concepts Review

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Imaging modalities in patients with slipped capital femoral epiphysis

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Abstract

Background Slipped capital femoral epiphysis (SCFE) is a frequent disorder of the adolescent hip, which may lead to avascular necrosis (AVN) of the femoral head, chondrolysis and early osteoarthritis due to the post-slip deformity of the proximal femur. To warrant the best possible outcome for the affected (and contralateral) hip, early diagnosis and proper treatment are needed.

Methods A review of the literature was undertaken to identify today's role of available imaging modalities in the management of SCFE.

Summary This review outlines the relevancy of different imaging modalities such as radiography, ultrasound, CT, MRI and bone scintigraphy in the treatment of SCFE patients. While standard radiography is the first-choice imaging modality for patients with suspected SCFE, ultrasound and advanced imaging modalities may aid in surgical planning, diagnosis of complications such as AVN and treatment follow-up.

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Introduction

Slipped capital femoral epiphysis (SCFE) is a frequent disorder of the adolescent hip,[1] in which the femoral metaphysis commonly displaces anteriorly, superiorly and laterally in relationship to the epiphysis. Male individuals are affected more frequently than females[1] and several predisposing factors that might lead to increased physeal susceptibility are known today.[1-7]

As a sequela of SCFE, severe complications such as avascular necrosis (AVN) of the femoral head, chondrolysis or early development of osteoarthritis in severe cases may occur. Therefore, early diagnosis of the disease and the application of proper treatment modalities are mandatory to warrant the best possible outcome for the affected hip. Additionally, given the high incidence of bilateral involvement, an exact analysis of the contralateral, initially non-slipped hip – including mechanical risk factors that may increase the risk for slippage – is required and should be included in the management of these patients.

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Diagnostic imaging

Radiography

Standard radiography is the first-choice imaging modality in patients with suspected SCFE. Usually, anteroposterior (AP) pelvis and frog-lateral views of both hips are obtained (Fig. 1). Radiographs of the contralateral side should always be included to rule out the bilateral involvement of SCFE. Further, the contralateral hip may serve as a control for the affected side. Notably, in acute, unstable slips rotation of the affected hip may cause pain (especially for frog-lateral view), increase the slip severity and, therefore, affect the outcome;[8,9] caution is recommended.

A cross-table view with the patient in a lateral position may decrease the patient's discomfort for obtaining a lateral view. Thus, all radiographs should be achieved

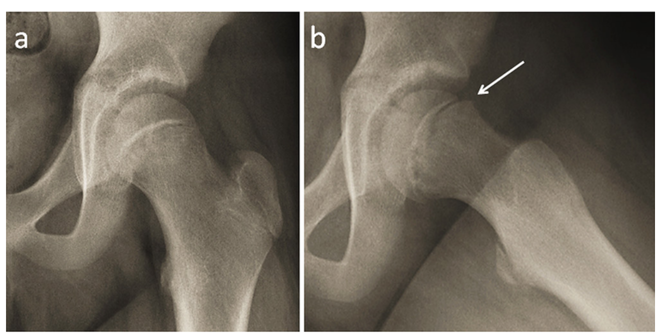

Fig. 1 Radiograph (anteroposterior (AP) and frog-lateral view) of a 13-year-old male SCFE patient. While the SCFE can be missed on AP films (**a**), the slip is obvious on frog-lateral view (**b**; arrow).

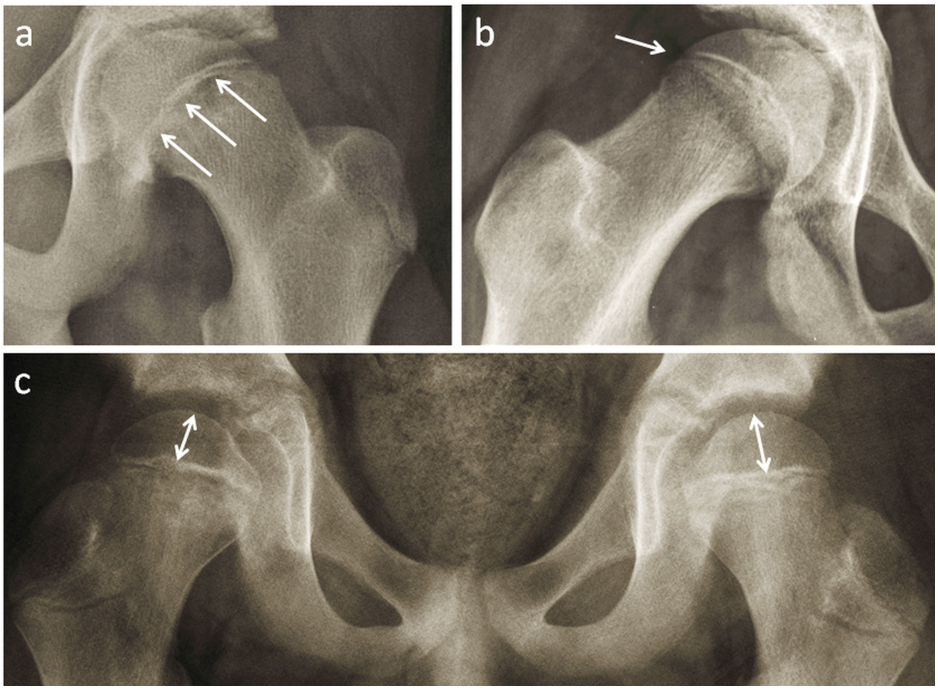

Fig. 2 Typical radiographic signs of SCFE: (**a**) widening with irregularities of the physis, (**b**) loss of concavity of the anterior femoral head-neck junction and (**c**) reduced height of the epiphysis compared with the contralateral, unaffected hip.

by a well-trained team of physicians and technicians with alternative imaging modalities being considered for unstable slips. Typical radiographic signs of SCFE (Fig. 2) may include:[10-13]

- widening and irregularities of the physis compared with the contralateral side;
- a relative loss of height of the epiphysis on AP projections;
- a loss of the anterior concavity of the femoral neck on lateral views;
- the 'metaphyseal blanch sign' (crescent-shaped area of increased density at the proximal and medial femoral neck as a result of the projection of the posterior portion of the femoral head which is displaced posteriorly, inferiorly and medially in relation to the metaphysis);
- cystic changes at the metaphysis, remodelling and periost reactions in cases of chronic SCFE;
- as a result of SCFE, chondrolysis with simultaneous changes in the subchondral bone of the femur and acetabulum may be found in all stages of SCFE.

Radiographic signs of SCFE at the physeal plate without evidence of epiphyseal displacement are referred to as imminent ('preslip') SCFE, with the beginning of slippage as incipient SCFE.

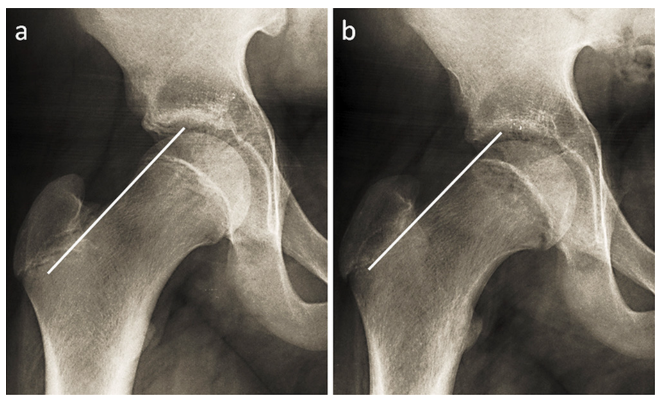

Fig. 3 (**a**) Kline's line is a tangent drawn parallel to the femoral neck that intersects the epiphysis in healthy hips. (**b**) In SCFE hips, Kline's line may not intersect with the epiphysis. In cases of mild slips, SCFE is diagnosed if the epiphyseal portion lateral to Kline's line differs by more than 2 mm compared with the contralateral hip.

Kline's line

Kline's line is a tangent drawn parallel to the superior margin of the femoral neck which, in healthy hips, usually intersects the epiphysis. In cases of SCFE, where the epiphysis is displaced medially in relation to the femoral neck, Kline's line may not intersect a portion of the femoral head (Fig. 3). This radiographic tool may help in diagnosing SCFE. However, in cases of mild slips, a modified approach with a comparison to the contralateral hip has shown better sensitivity (SCFE is diagnosed if the portion of the epiphysis lateral to Kline's line differs by more than 2 mm compared with the contralateral side).[14]

Ultrasound

As a non-invasive tool, bilateral ultrasound should be used routinely in any case of suspected SCFE. The epiphyseal displacement may be indicated as a visible step between the epiphysis and the metaphysis. Additionally, capsule distension and intra-articular effusion of the affected hip may indicate an acute/unstable SCFE (Fig. 4).[15]

MRI and CT

The role of MRI and CT in the diagnosis of SCFE remains controversial and the indication for cross-sectional imaging modalities should be scrutinised thoroughly from case to case to avoid an unnecessary delay of proper treatment introduction, especially in acute cases. Particularly in early cases of SCFE, MRI is more sensitive than conventional radiography (Fig. 5). MRI signs of an imminent slip include widening of the physis, bone marrow oedema (Fig. 6), joint effusion and synovitis,[16-18] and may prevent further slippage as surgical intervention and stabilisation of the physis can be introduced immediately. Depending on the MRI settings, diffusion imaging may depict the vascularity of the femoral head and the extent of pre-existing AVN.[19] This might be of importance not only to assess the prognostic outcome for the patient but also to reveal the presence of pre-existing AVN prior to surgery.

Including three-dimensional reconstruction, CT imaging can help to understand the post-slip deformity of the proximal femur. Therefore, CT imaging should be considered especially in cases of severe SCFE before re-aligning surgical approaches. Additionally, axial and sagittal CT reformats may serve for analysis of underlying acetabular and femoral morphology that increases the risk of slippage in the contralateral hip. Previously reported data revealed femoral[20,21] and acetabular retroversion [22,23] as a risk factor for SCFE while the data on acetabular coverage remain controversial.[23,24] Notably, as femoral retroversion[25] and femoroacetabular impingement (FAI)[26] have both been associated with acetabular retroversion, it still remains unclear whether increased acetabular retroversion has to be seen as a distinct primary morphology in the development of SCFE that increases the mechanical risk of the hip or as a secondary adaption mechanism.

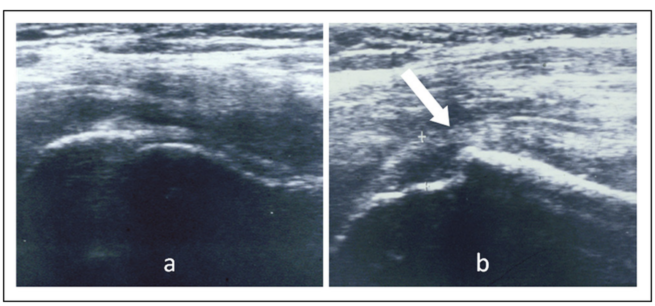

Fig. 4 Ultrasound of (**a**) a contralateral, unaffected hip and (**b**) a SCFE hip. Ultrasound reveals the epiphyseal displacement with intra-articular effusion and consecutive capsule distension (arrow).

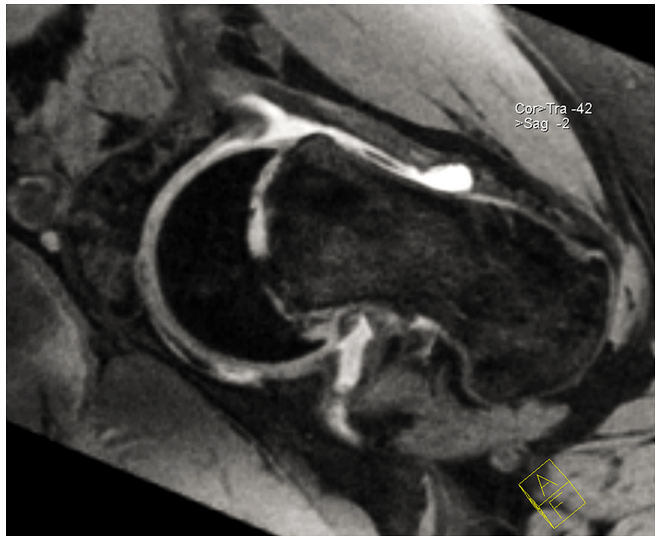

Fig. 5 Acute SCFE in a 15-year-old male patient. Radially reformatted MR images (double echo steady state sequence) with the femoral neck axis as the centre of rotation (shown here is the 1 o'clock position) depict the severity of posterior slippage, widening of the physis and joint effusion.

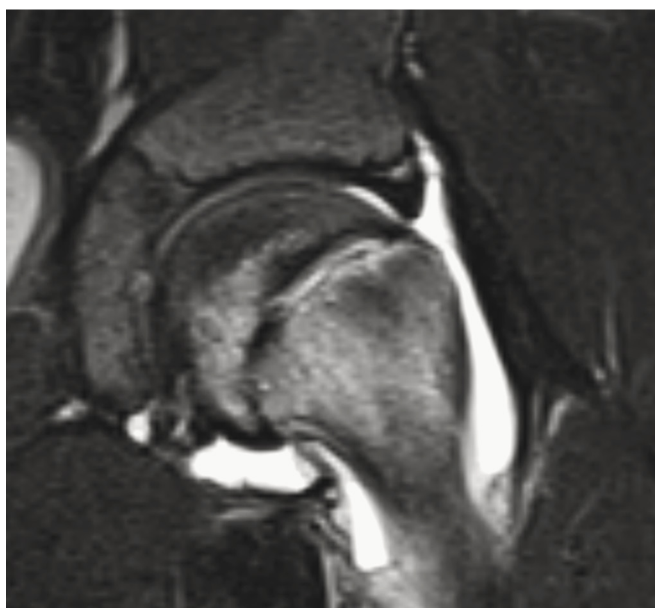

Fig. 6 In the same case (also see Fig. 5) of a 15-year-old male patient with acute SCFE, associated bone marrow oedema is picked up by the STIR (short tau inversion recovery) sequence. Bone marrow oedema may be an early sign of avascular necrosis.

Classification and slip severity

SCFE can be classified according to its stability, acuity and severity. According to Loder, the SCFE is considered unstable if the patient is unable to ambulate (with or without crutches) and vice versa.[27,28]

If symptoms are reported for longer than three weeks, the SCFE is called chronic, which accounts for the majority of cases (approximately 75%). If symptoms are present for less than three weeks, the SCFE is called acute (approximately 10%). Acute on chronic SCFE denotes a history of prodromal symptoms, sometimes with an asymptomatic interval, which has been present for more than three weeks with a sudden, acute pain exacerbation.[29,30]

Southwick angle

The slip severity characterises the amount of epiphyseal displacement. It is usually described by the Southwick angle, which is measured on frog-lateral views (Fig. 7). The Southwick angle is defined as the angle between a line perpendicular to a line that connects the anterior and posterior margins of the physis and a line along the axis of the femoral shaft. To assess the amount of posterior angulation of the head with respect to the neck, the Southwick angle of the hip unaffected by SCFE is subtracted from the SCFE side. In cases of bilateral slippage an angle of 12° is used as reference. The severity is then classified as mild (0° to 30°), moderate (30° to 50°) or severe (> 50°).[31]

Posterior sloping angle

With varying numbers previously reported in the literature, the frequency of bilateral involvement in SCFE is undoubtedly high.[32-35] However, management of the contralateral, initially non-slipped hip remains controversial.[36] As a predictor of bilaterality, the posterior sloping angle (PSA; the angle between a line that connects the anterior and posterior margins of the physis and a line perpendicular to the longitudinal axis of the femur on frog-lateral view; Fig. 7) has been described by Barrios et al.[37] PSA values in the range of 12° to 15° have been reported as objective thresholds to predict contralateral SCFE and to advocate prophylactic pinning.[37-40]

A recently published study by Boyle et al[41] noted a significant correlation between the PSA and the time to contralateral SCFE (correlation coefficient -0.48; p = 0.001). Interestingly, multivariable analyses in that study revealed the alpha angle as described by Nötzli et al[42] to be the only independent risk factor for contralateral SCFE (p = 0.004). The authors noted an increase in the relative odds for bilateral slippage by 10% for each degree of increase in alpha angle in their population.

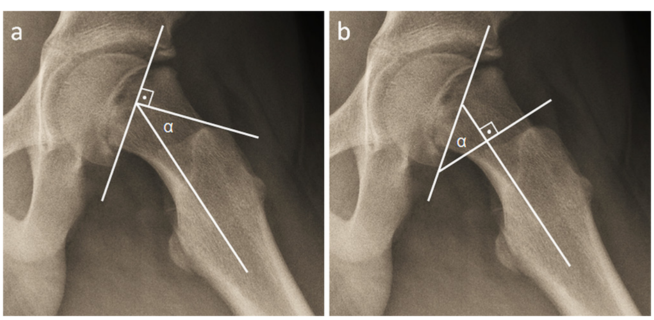

Fig. 7 (**a**) Southwick and (**b**) Posterior sloping angle (PSA) on frog-lateral radiographs. The Southwick angle is defined as the angle between a line along the axis of the femoral shaft and a line perpendicular to the line that connects the anterior and posterior margins of the epiphysis. The PSA is measured between a line that connects the anterior and posterior margins of the epiphysis and a line perpendicular to the axis of the femoral shaft.

Post-operative follow-up, residual deformity and complications

In cases of mild and moderate SCFE, *in situ* pinning is performed in the affected and – in most centres across Europe – in the contralateral hip prophylactically. Although surgery – and associated complications such as infection, bone fracture, AVN or chondrolysis – on a potentially healthy hip joint remains controversial, an analysis in a cohort of 94 SCFE patients with a unilateral slip revealed a favourable risk-benefit profile for prophylactically pinning the contralateral hip with K-wires.[43] No matter which fixation technique is used (e.g. screw, K-wire, Hansson Pin), hardware positioning should be perpendicular to the physis and placement in the anterior-superior quadrant of the femoral head should be avoided due to the risk of AVN. If techniques have been used that allow for physeal growth, routine radiography follow-ups (AP, frog-lateral) should be obtained to ensure transphyseal fixation. In cases of growing off, re-fixation is needed as decreased physeal stability might facilitate slip progression.[44] Further assessment should include residual deformity of the joint and remodelling (Fig. 8). According to Jones et al, the likelihood of remodelling is inversely related to slip severity and is significantly increased if the triradiate cartilage is open at presentation.[45] This is important, as the residual deformity of the proximal femur following SCFE is prone to cause FAI with early damage to acetabular cartilage.[46-48] Notably, in a study on 29 patients with unilateral unstable SCFE, who underwent *in situ* pinning of the affected and unaffected hips with K-wires, radiological evaluation at a mean follow-up of 3.5 years revealed asphericity of the femoral head only in SCFE-affected hips but not in prophylactically pinned hips.[49] These results indicate that the slippage of the epiphysis but not prophylactic transfixation of the epiphysis may lead to impairment of the femoral growth plate. Further criteria to assess the post-slip

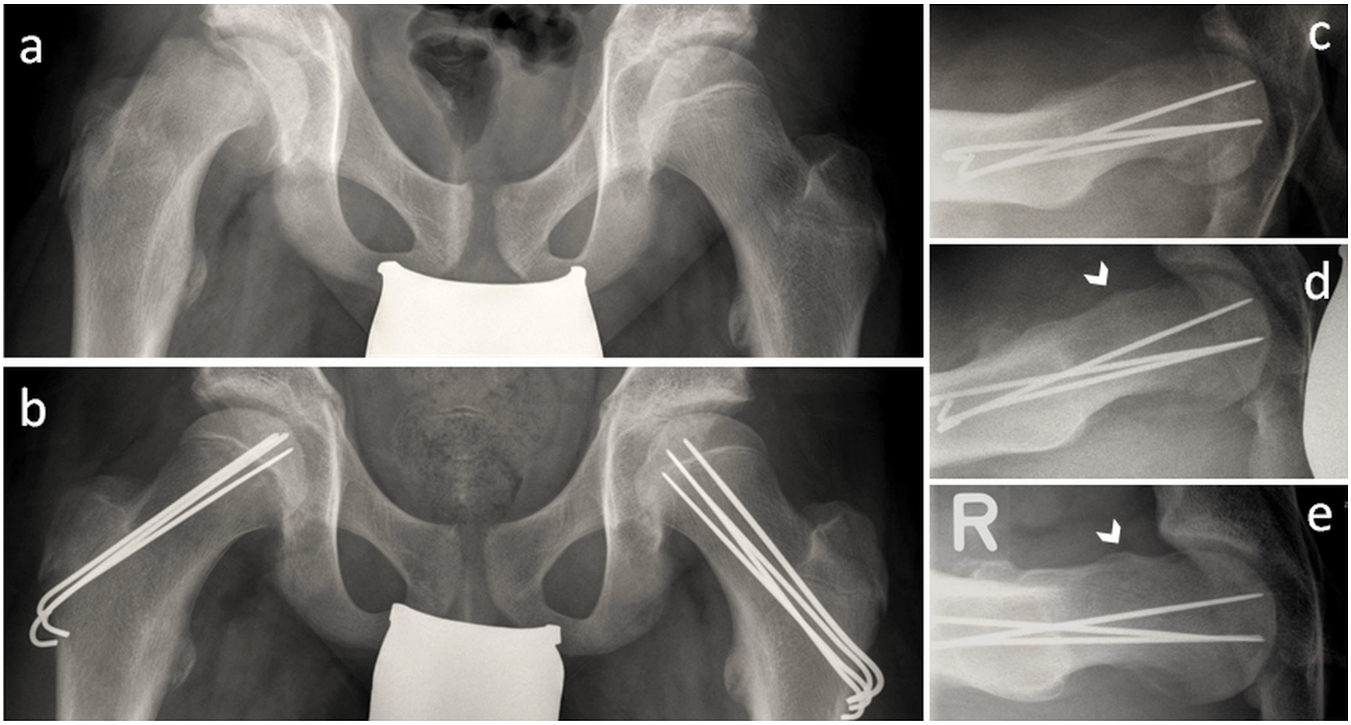

Fig. 8 (**a**) Acute SCFE of the right hip in a 14-year-old male. (**b**) After closed reduction, transphyseal fixation of both hips with K-wires was performed. Radiographic follow-ups (**c**) postoperatively, (**d**) six months after SCFE and (**e**) two years after SCFE depict remodelling with the typical post-slip deformity at the anterior-superior head/neck junction (arrows).

deformity of the hip joint are the alpha angle, the length of the femoral neck, the femoral head/neck angle, the articulotrochanteric distance and the centrotrochanteric distance.[42,50-53]

Avascular necrosis

While Loder et al did not observe any cases of AVN following stable SCFE,[27] the reported prevalence in unstable cases is in the range of 3% to 58%.[27,54-56] AVN may occur early in acute cases but onset of symptoms may also be delayed for up to ten months. Typical radiographic signs of AVN include areas of varying bone density, sclerosis, subcortical fracture ('crescent sign') and a loss of congruency of the femoral head. Although MRI can depict early changes in the course of AVN such as bone marrow oedema, post-operative assessment by MRI is often impaired due to surgical implants. With excellent sensitivity and predictive value for the detection of early AVN, a bone scan has been shown to pick up early changes in the development of AVN, long before radiographic changes are notable.[57] With MRI and bone scan being considered as the standard imaging techniques for detecting AVN of the femoral head, positron emission tomography (PET) has been shown with good sensitivity for detection of concomitant acetabular AVN in a population of 11 patients with atraumatic AVN of the femoral head.[58] However, given the costs of this time-consuming technique, future studies are needed to identify the role of PET imaging in the setting of suspected AVN in a SCFE population.

Chondrolysis

Radiographic signs of chondrolysis include joint space narrowing and generalised osteopenia. While some authors advocate the slip severity and early osteotomies as risk factors for chondrolysis,[59,60] the prevalence following *in situ* pinning has been reported as 1.5%.[61] As a complication following screw/pin fixation of the epiphysis, intra-articular placement of hardware is a major risk factor for chondrolysis and should be avoided under all circumstances.

Advanced imaging

Over the past decade, various biochemically sensitive MRI techniques have evolved, each targeting different molecular changes or interactions in the composition of articular cartilage. These methods include, for example, delayed gadolinium-enhanced MRI of cartilage (dGEMRIC),[62] T1rho[63] and gagCEST,[64] each sensitive to the cartilage glycosaminoglycan content as well as T2[65] and T2* imaging[66] that depend on the cartilage water content and interactions between water molecules and the collagen fibre network. Particularly in the anterior-superior aspect of the hip joint, where the post-slip deformity can facilitate

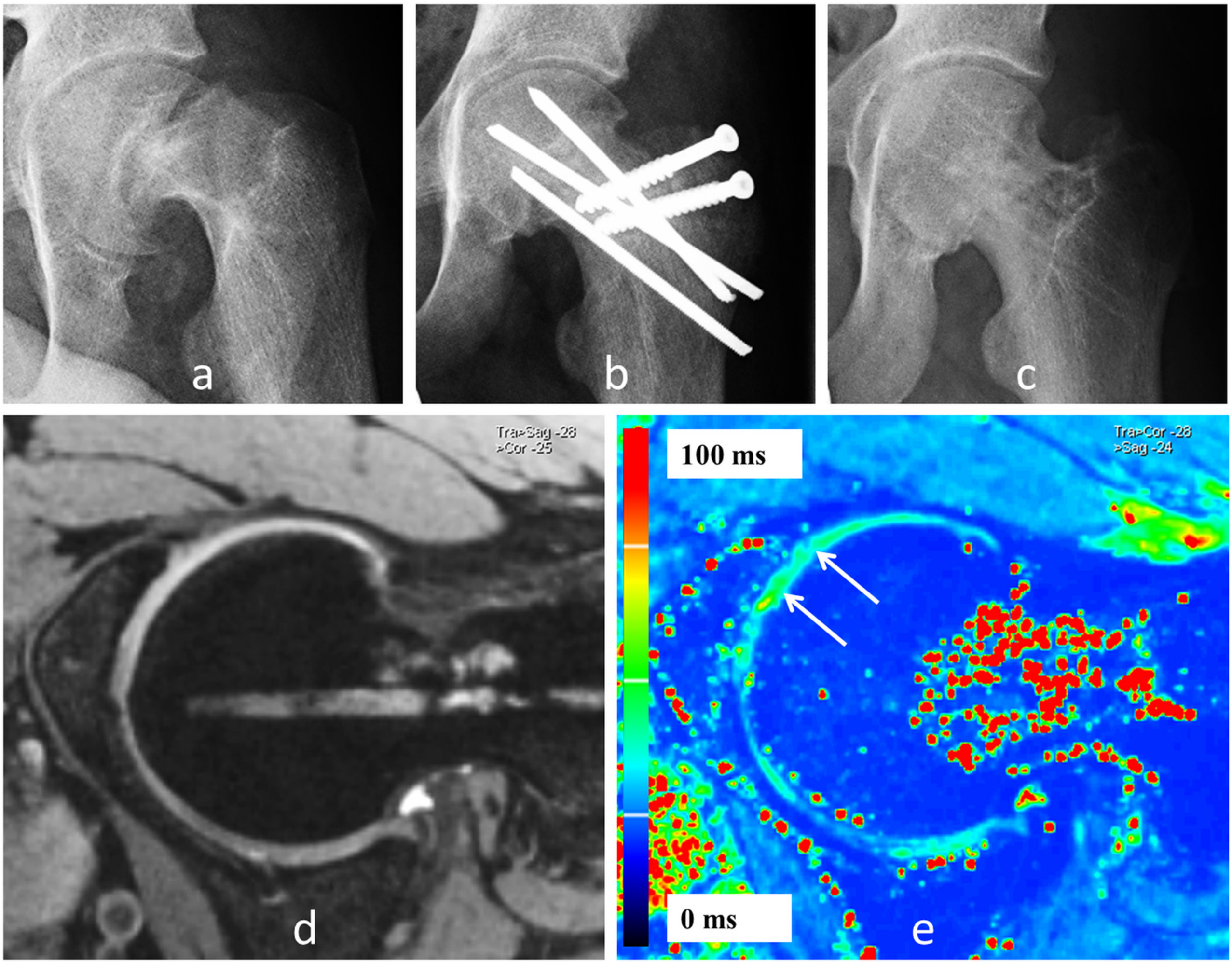

Fig. 9 (**a**) Severe, acute on chronic SCFE in a 15-year-old male patient with severe deformity of the proximal femur. (**b**) Capital realignment surgery was conducted via a modified Dunn procedure introduced by R. Ganz with restoration of the femoral head-neck offset. (**c**) Following hardware removal, isotropic three-dimensional evaluation of hip joint cartilage reveals no apparent cartilage damage in the anterior-superior (2 o'clock position) aspect of the hip joint as shown by (**d**) radially reformatted double echo steady state and (**e**) corresponding T2* reformats.

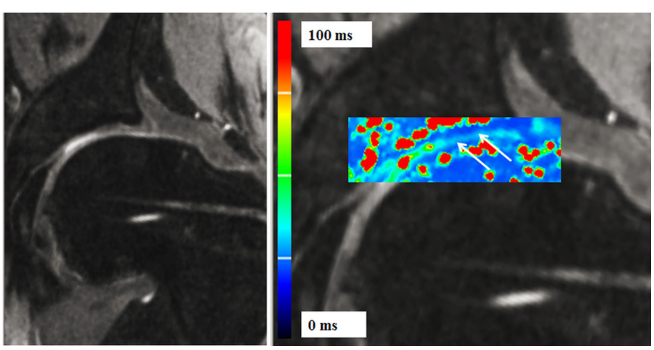

Fig. 10 In the setting of pending hip surgery for restoration of femoral head-neck offset in a 14-year-old female patient following *in situ* fixation for chronic SCFE, radially reformatted double echo steady state and superimposed T2* analysis of the superior-anterior (1 o'clock position) hip joint clearly depicts acetabular cartilage damage and the corresponding asphericity of the femoral head.

FAI and lead to cartilage degeneration and early osteoarthritis, these imaging techniques hold promise to objectively assess the cartilage status in a reproducible manner (Fig. 9). Further, including the value of radial imaging and three-dimensional reconstruction, these techniques will possibly help to guide surgical treatment according to the individual disease/deformity and to monitor surgical and non-surgical treatment strategies (Fig. 10).

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COMPLIANCE WITH ETHICAL STANDARDS

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