Imaging modalities in patients with slipped capital femoral epiphysis

T. Hesper  
C. Zilkens  
B. Bittersohl  
R. Krauspe

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.

Cite this article: Hesper T, Zilkens C, Bittersohl B, Krauspe R. Imaging modalities in patients with slipped capital femoral epiphysis. J Child Orthop 2017;11:99-106. DOI 10.1302/1863-2548.11.160276

Keywords: Slipped capital femoral epiphysis; SCFE; imaging modalities

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 females¹ 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.

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...
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:

- 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. 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.

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).\textsuperscript{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).\textsuperscript{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,\textsuperscript{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.\textsuperscript{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 reformatting 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\textsuperscript{20,21} and acetabular retroversion\textsuperscript{22,23} as a risk factor for SCFE while the data on acetabular coverage remain controversial.\textsuperscript{23,24} Notably, as femoral retroversion\textsuperscript{25} and femoroacetabular impingement (FAI)\textsuperscript{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 adaptation mechanism.

![Fig. 4](image1.png)

**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](image2.png)

**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](image3.png)

**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 axis of the femoral shaft) 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.17 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 al11 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 al42 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.

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
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 T1rho63 and gagCEST,64 each sensitive to the cartilage glycosaminoglycan content as well as T265 and T2* imaging66 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. 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).
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).

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.
IMAGING MODALITIES IN PATIENTS WITH SLIPPED CAPITAL FEMORAL EPIPHYSIS

REFERENCES

1. Loder RT. The demographics of slipped capital femoral epiphysis. An international multicenter study. Clin Orthop Relat Res 1996;322:8-27.
2. McAfee PC, Cady RB. Endocrinologic and metabolic factors in atypical presentations of slipped capital femoral epiphysis. Report of four cases and review of the literature. Clin Orthop Relat Res 1983;180:188-197.
3. Aronson DD, Loder RT. Slipped capital femoral epiphysis in black children. J Pediatr Orthop 1992;12:74-79.
4. Wells D, King JD, Roe TF, Kaufman FR. Review of slipped capital femoral epiphysis associated with endocrine disease. J Pediatr Orthop 1993;13:610-614.
5. Murray AW, Wilson NL. Changing incidence of slipped capital femoral epiphysis: a relationship with obesity? J Bone Joint Surg [Br] 2008;90-B:92-94.
6. Zupanc O, Krizancic M, Daniel M, et al. Shear stress in epiphyseal growth plate as a risk factor for slipped capital femoral epiphysis. J Pediatr Orthop 2008;28:444-451.
7. Witbreuk M, van Kemenade FJ, van der Sluijs JA, et al. Slipped capital femoral epiphysis and its association with endocrine, metabolic and chronic diseases: a systematic review of the literature. J Child Orthop 2013;7:213-223.
8. Broughton NS, Todd RC, Dunn DM, Angel JC. Open reduction of the severely slipped upper femoral epiphysis. J Bone Joint Surg [Br] 1988;70-B:435-439.
9. Upasani VV, Matheney TH, Spencer SA, et al. Complications after modified Dunn osteotomy for the treatment of adolescent slipped capital femoral epiphysis. J Pediatr Orthop 2014;34:661-667.
10. Klein A, Joplin RJ, Reidy JA, Hanelin J. Roentgenographic features of slipped capital femoral epiphysis. Am J Roentgenol Radium Ther 1991;66:361-374.
11. Steel HH. The metaphyseal blanch sign of slipped capital femoral epiphysis. J Bone Joint Surg [Am] 1986;68-A:920-922.
12. Lubicky JP. Chondrolysis and avascular necrosis: complications of slipped capital femoral epiphysis. J Pediatr Orthop B 1996;5:162-167.
13. Gekeler J. [Radiology and measurement in adolescent slipped capital femoral epiphysis]. Orthopade 2002;31:841-852. (In German)
14. Green DW, Mogekwu N, Scher DM, et al. A modification of Klein’s Line to improve sensitivity of the anterior-posterior radiograph in slipped capital femoral epiphysis. J Pediatr Orthop 2009;29:449-453.
15. Castriota-Sanderbeg A, Orsi E. Slipped capital femoral epiphysis: ultrasonographic findings. Skeletal Radiol 1993;22:191-193.
16. Umans H, Liebling MS, Moy L, et al. Slipped capital femoral epiphysis: a physeal lesion diagnosed by MRI, with radiographic and CT correlation. Skeletal Radiol 1998;27:139-144.
17. Lalaji A, Umans H, Schneider R, et al. MRI features of confirmed “pre-slip” capital femoral epiphysis: a report of two cases. Skeletal Radiol 2002;31:362-365.
18. Tins B, Cassar-Pullicino V, McCall I. The role of pre-treatment MRI in established cases of slipped capital femoral epiphysis. Eur J Radiol 2009;70:570-578.
19. Mueller D, Schaeffeler C, Baum T, et al. Magnetic resonance perfusion and diffusion imaging characteristics of transient bone marrow edema, avascular necrosis and subchondral insufficiency fractures of the proximal femur. Eur J Radiol 2014;83:1862-1869.
20. Gelberman RH, Cohen MS, Shaw BA, et al. The association of femoral retroversion with slipped capital femoral epiphysis. J Bone Joint Surg [Am] 1986;68-A:1000-1007.
21. Pritchett JW, Perdue KD. Mechanical factors in slipped capital femoral epiphysis. J Pediatr Orthop 1988;8:385-388.
22. Bauer JP, Roy DR, Thomas SS. Acetabular retroversion in post slipped capital femoral epiphysis deformity. J Child Orthop 2013;7:91-94.
23. Monazzam S, Krishnamoorthy V, Bittersohl B, Bomar JD, Hosalkar HS. Is the acetabulum retroverted in slipped capital femoral epiphysis? Clin Orthop Relat Res 2013;471:2145-2150.
24. Kordellie J, Richolt JA, Millis M, Jolesz FA, Kikinis R. Development of the acetabulum in patients with slipped capital femoral epiphysis: a three-dimensional analysis based on computed tomography. J Pediatr Orthop 2001;21:174-178.
25. Buller LT, Rosneck J, Monaco FM, et al. Relationship between proximal femoral and acetabular alignment in normal hip joints using 3-dimensional computed tomography. Am J Sports Med 2012;40:367-375.
26. Siebenrock KA, Schoeniger R, Ganz R. Anterior femoro-acetabular impingement due to acetabular retroversion. Treatment with periacetabular osteotomy. J Bone Joint Surg [Am] 2003;85-A:278-286.
27. Loder RT, Richards BS, Shapiro PS, Reznick LR, Aronson DD. Acute slipped capital femoral epiphysis: the importance of physesal stability. J Bone Joint Surg [Am] 1993;75-A:1134-1140.
28. Loder RT. What is the cause of avascular necrosis in unstable slipped capital femoral epiphysis and what can be done to lower the rate? J Pediatr Orthop 2013;33:586-591.
29. Aadalen RJ, Weiner DS, Hoyt W, Herndon CH. Acute slipped capital femoral epiphysis. J Bone Joint Surg [Am] 1974;56-A:1473-1487.
30. Wensaa S, Svenningsen S, Terjesen T. Long-term outcome of slipped capital femoral epiphysis: a 38-year follow-up of 66 patients. J Child Orthop 2011;5:75-82.
31. Loder RT, Aaronsodd DD, Dobbs MB, Weinstein SL. Slipped capital femoral epiphysis. Instr Course Lect 2001;50:555-570.
32. Hägglund G. The contralateral hip in slipped capital femoral epiphysis. J Pediatr Orthop B 1996;5:158-161.
33. Jerre R, Billing L, Hansson G, Karlsson J, Wallin J. Bilaterality in slipped capital femoral epiphysis: importance of a reliable radiographic method. J Pediatr Orthop B 1996;5:80-84.
34. Castro FP Jr, Bennett JT, Doulens K. Epidemiologic perspective on prophylactic pinning in patients with unilateral slipped capital femoral epiphysis. J Pediatr Orthop 2000;20:745-748.
Kocher MS, Bishop JA, Hresko MT, et al. Prophylactic pinning of the contralateral hip after unilateral slipped capital femoral epiphysis. J Bone Joint Surg (Am) 2004;86-A:2658-2665.

Sankar WN, Novais EN, Lee C, et al. What are the risks of prophylactic pinning to prevent contralateral slipped capital femoral epiphysis? Clin Orthop Relat Res 2013;471:218-223.

Barrios C, Blasco MA, Blasco MC, Gascó J. Posterior sloping angle of the capital femoral physis: a predictor of bilaterality in slipped capital femoral epiphysis. J Pediatr Orthop 2005;25:445-449.

Park S, Hsu JE, Rendon N, Wolfgruber H, Wells L. The utility of posterior sloping angle in predicting contralateral slipped capital femoral epiphysis. J Pediatr Orthop 2010;30:683-689.

Phillips PM, Phadnis J, Willoughby R, Hunt L. Posterior sloping angle as a predictor of contralateral slip in slipped capital femoral epiphysis. J Bone Joint Surg (Am) 2013;95:146-150.

Bellemore JM, Carpenter EC, Yu NY, Birke O, Little DG. Biomechanics of slipped capital femoral epiphysis: evaluation of the posterior sloping angle. J Pediatr Orthop 2016;36:651-655.

Boyle MJ, Lirola JF, Hogue GD, et al. The alpha angle as a predictor of contralateral slipped capital femoral epiphysis. J Child Orthop 2016;10:201-207.

Nötzli HP, Wyss TF, Stoecklin CH, et al. The contour of the femoral head-neck junction as a predictor for the risk of anterior impingement. J Bone Joint Surg (Br) 2002;84-B:556-560.

Seller K, Raab P, Wild A, Krauspe R. Risk-benefit analysis of prophylactic pinning in slipped capital femoral epiphysis. J Pediatr Orthop B 2001;10:192-196.

Givon U, Bowen JR. Chronic slipped capital femoral epiphysis: treatment by pinning in situ. J Pediatr Orthop B 1999;8:216-222.

Jones JR, Paterson DC, Hillier TM, Foster BK. Remodelling after pinning for slipped capital femoral epiphysis. J Bone Joint Surg (Br) 1999;72-B:568-573.

Leunig M, Casillas MM, Hamlet M, et al. Slipped capital femoral epiphysis: early mechanical damage to the acetabular cartilage by a prominent femoral metaphysis. Acta Orthop Scand 2000;71:370-375.

Dodds MK, McCormack D, Mulhall KJ. Femoroacetabular impingement after slipped capital femoral epiphysis: does slip severity predict clinical symptoms? J Pediatr Orthop 2009;29:535-539.

Sink EL, Zaltz I, Heare T, Dayton M. Acetabular cartilage and labral damage observed during surgical hip dislocation for stable slipped capital femoral epiphysis. J Pediatr Orthop 2010;30:26-30.

Seller K, Wild A, Westhoff B, Raab P, Krauspe R. Radiological evaluation of unstable (acute) slipped capital femoral epiphysis treated by pinning with Kirschner wires. J Pediatr Orthop B 2006;15:328-334.

Hansson LI. Osteosynthesis with the hook-pin in slipped capital femoral epiphysis. Acta Orthop Scand 1982;53:87-96.

Segal LS, Davidson RS, Robertson WW Jr, Drummond DS. Growth disturbances of the proximal femur after pinning of juvenile slipped capital femoral epiphysis. J Pediatr Orthop 1997;17:651-657.

Laplaza FJ, Burke SW. Epiphyseal growth after pinning of slipped capital femoral epiphysis. J Pediatr Orthop 1995;15:357-361.

Oppenheim WL, Bowen RE, McDonough PW, Funahashi TT, Salusky IB. Outcome of slipped capital femoral epiphysis in renal osteodystrophy. J Pediatr Orthop 2003;23:169-174.

Kennedy JG, Hresko MT, Kasser JR, et al. Osteonecrosis of the femoral head associated with slipped capital femoral epiphysis. J Pediatr Orthop 2001;21:189-193.

Tokmakova KP, Stanton RP, Mason DE. Factors influencing the development of osteonecrosis in patients treated for slipped capital femoral epiphysis. J Bone Joint Surg (Am) 2003;85-A:798-801.

Palocaren T, Holmes L, Rogers K, Kumar S. Outcome of in situ pinning in patients with unstable slipped capital femoral epiphysis: assessment of risk factors associated with avascular necrosis. J Pediatr Orthop 2010;30:31-36.

Fragnière B, Chotel F, Vargas Barreto B, Bérard J. The value of early postoperative bone scan in slipped capital femoral epiphysis. J Pediatr Orthop B 2003;12:51-55.

Dasa V, Adbel-Nabi H, Anders MJ, Mihalko WM. F-18 fluoride positron emission tomography of the hip for osteonecrosis. Clin Orthop Relat Res 2008;466:1081-1086.

Ingram AJ, Clarke MS, Clarke CS Jr, Marshall WR. Chondrolysis complicating slipped capital femoral epiphysis. Clin Orthop Relat Res 1982;165:99-109.

Jofe MH, Lehman W, Ehrlich MG. Chondrolysis following slipped capital femoral epiphysis. J Pediatr Orthop B 2004;13:29-31.

Kennedy JP, Weiner DS. Results of slipped capital femoral epiphysis in the black population. J Pediatr Orthop 1990;10:224-227.

Zilkens C, Miese F, Bittersohl B, et al. Delayed gadolinium-enhanced magnetic resonance imaging of cartilage (dGEMRIC), after slipped capital femoral epiphysis. Eur J Radiol 2011;77:400-406.

Wyatt C, Kumar D, Subburaj K, et al. Cartilage T1p and T2 relaxation times in patients with mild-to-moderate radiographic hip osteoarthritis. Arthritis Rheumatol 2015;67:1548-1556.

Singh A, Haris M, Cai K, et al. Chemical exchange saturation transfer magnetic resonance imaging of human knee cartilage at 3 T and 7 T. Magn Reson Med 2012;68:588-594.