Eur Radiol (2007) 17: 163–168
DOI 10.1007/s00330-006-0261-y

PEDIATRIC

G. Staatz
D. Honnef
A. Kochs
C. Hohl
T. Schmidt
H. Röhrig
R. W. Günther

Evaluation of femoral head vascularization in slipped capital femoral epiphysis before and after cannulated screw fixation with use of contrast-enhanced MRI: initial results

Received: 29 June 2005
Revised: 7 March 2006
Accepted: 16 March 2006
Published online: 20 April 2006

G. Staatz (✉)
Department of Radiology,
Division of Pediatric Radiology,
Friedrich-Alexander-University
Erlangen-Nürnberg,
Loschgestr._15,
91054 Erlangen, Germany
e-mail: gu.stz.uni-erlangen@t-online.de
Tel.: +49-9131-8533134
Fax: +49-9131-8533895

G. Staatz · D. Honnef · C. Hohl ·
T. Schmidt · R. W. Günther
Department of Diagnostic Radiology,
University Hospital of the RWTH
Aachen, Aachen, Germany

A. Kochs · H. Röhrig
Department of Orthopaedic Surgery,
University Hospital of the RWTH
Aachen, Aachen, Germany

Abstract In this study we used contrast-enhanced magnetic resonance imaging (MRI) to evaluate the vascularization of the femoral head in children with slipped capital femoral epiphysis (SCFE) before and after cannulated screw fixation. Eleven consecutive children with SCFE, seven boys and four girls, aged 10–15 years were included in the study. There were no preslips; four children had acute, three acute-on-chronic, and four chronic SCFE. The MRI examinations were performed in a 1.5 Tesla MR scanner with use of a coronal STIR sequence, a coronal contrast-enhanced T1-weighted spin-echo sequence, and a sagittal three-dimensional gradient-echo sequence. Morphology, signal intensities, and contrast-enhancement of the femoral head were assessed by two radiologists in consensus. Morphologic distortion of the physis, bone marrow edema within the metaphysis and epiphysis, and joint effusion were the preoperative MRI findings of SCFE in each child. In nine children, the vascularization of the femoral head before and after surgery was normal. In one child, a preoperative avascular zone in the superolateral aspect of the epiphysis revascularized completely after surgery. One child with severe SCFE developed avascular necrosis of the femoral head after open reduction of the slip. We conclude that MRI allows for accurate evaluation of the femoral head vascularization before and after surgery in children with SCFE.

Keywords Slipped capital femoral epiphysis · Magnetic resonance imaging · Hip · Necrosis · Children · Skeletal system

Introduction

Slipped capital femoral epiphysis (SCFE) is a typical disease of puberty with a reported prevalence of up to 10 per 100,000 [1, 2]. Although the etiology of SCFE is unknown, the condition may be associated with biomechanical factors, such as obesity, increased femoral retroversion, and increased physeal obliquity, or with endocrine disorders such as hypothyroidism and hypogonadism [3]. The goal of treatment is to prevent additional slippage while avoiding the complications of avascular necrosis and chondrolysis. In situ fixation with multiple pins has a high complication rate, with the development of additional slippage, chondrolysis, and avascular necrosis in up 20–40% of cases, whereas in situ fixation of SCFE with cannulated titanium screws provides better results [2, 4, 5]. Because of only minor susceptibility artifacts in contrast to pins, the use of titanium screws enables surgically treated hips to be assessed by magnetic resonance imaging (MRI) [6]. The purpose of this study was to use contrast-enhanced MRI to evaluate the femoral head vascularization before and after cannulated screw fixation.

Materials and methods

Eleven consecutive children with SCFE, seven boys and four girls age 10–15 years, were included in the study. Their diagnoses were based on the findings of the

radiographs, of which anteroposterior and lateral frog-leg (Lauenstein) views were obtained in each child. The classification of SCFE was done traditionally according to patient history, physical examination, and radiographic findings. The severity of the slip was determined by the lateral head-shaft angle as described by Southwick [7]. This slip angle is measured on the frog-leg lateral radiograph and describes the difference between the femoral shaft and a perpendicular of the femoral epiphysis.

All preoperative MR examinations were carried out within 2 weeks before surgery (mean time 3.8 days), and the postoperative MRI examinations were carried out within 8 weeks after surgery (mean time 31.7 days). The MRI examinations were performed in a 1.5 Tesla MR scanner (Philips, Best, Netherlands) using the magnet's body coil and with the unsedated children placed in supine position. The examination protocol included a coronal fat-suppressed short tau inversion recovery (STIR) sequence, a coronal contrast-enhanced T1-weighted spin-echo (T1SE) sequence with subtraction images, and a sagittal three-dimensional (3D) gradient-echo (FFE) sequence (cartilage-sensitive). The scan parameters of the sequences were as follows: STIR: TR 1,400–1,600 ms, TE 30–60 ms, TI 110–120 ms, TSE factor 10–12, slice thickness 3–4 mm, NEX 4–6, matrix 226:256. T1SE: TR 524–600 ms, TE 15–21 ms, slice thickness 3–4 mm, NEX 2–3, matrix 179:256–256:512. FFE: TR 60 ms, TE 14–18 ms, slice thickness 3.0–3.4 mm, NEX 2–4, matrix 212:256–228:512.

For contrast enhancement, gadolinium (Magnevist, Schering, Berlin, Germany) 0.1 mmol/kg body weight was injected intravenously. Morphology, signal intensities, and contrast enhancement of the femoral heads were assessed retrospectively by two experienced radiologists in consensus.

All patients underwent surgery within 2 weeks (mean time 3.8 days) after assessment of the diagnosis and performance of the preoperative contrast-enhanced MRI examination. In nine children, bilateral in situ fixation of the epiphysis with cannulated titanium screws (Königsee Surgical Implants and Instruments for Osteosynthesis, Aschau, Germany) was performed. The length of the inserted screws varied between 90 and 120 mm, the thread diameter was 7.0 mm, and the thread length measured 16 mm (Fig. 1). A 9-year-old boy underwent open reduction and internal fixation of the SCFE with two screws on the left side and in situ fixation with a single screw of the right epiphysis. In one child with acute-on-chronic and severe SCFE on the left side, open reduction and corrective osteotomy through the physis with subsequent cannulated screw fixation were carried out, whereas the contralateral epiphysis was fixed prophylactically with a single cannulated screw. All children underwent clinical follow-up for at least 1 year (mean follow-up time 2.1 years).

Results

The classification of SCFE in our patients revealed no preslips. Four children had acute SCFE, three had acute-on-chronic SCFE, and four had chronic SCFE. The head-shaft angles of the affected hips varied between 16 and 72 degrees, representing mild to moderate SCFE in nine and severe SCFE in two children. The preoperative MRI examinations showed morphologic distortion of the physis, bone marrow edema in the metaphysis and epiphysis, and joint effusion within the hip with SCFE in each child (Fig. 2). In chronic SCFE, the bone marrow edema and the hip effusion were less pronounced.

Postoperative MRI of the hips was feasible in each child, with only minor susceptibility artifacts due to the inserted cannulated titanium screws. The bone marrow of the hips

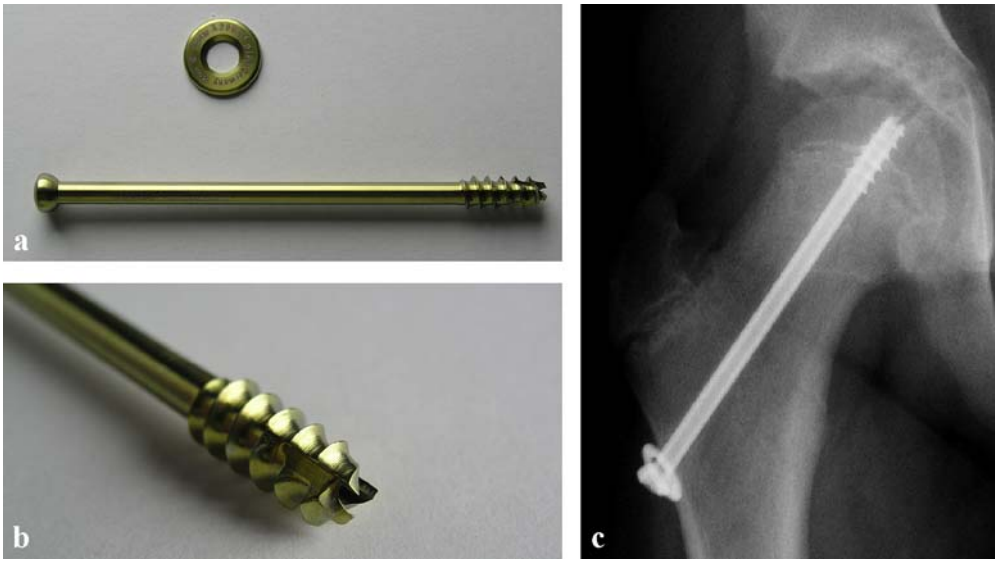

Fig. 1 Cannulated titanium screw (**a**, **b**) and radiograph (**c**) after insertion of a single screw into the right hip

Fig. 2 A 12-year-old girl with acute slipped capital femoral epiphysis of the right hip. The short tau inversion recovery image (**a**) demonstrates joint effusion, distortion of the epiphysis, and bone marrow edema of the metaphysis and epiphysis adjacent to the physis. The postoperative contrast-enhanced T1-weighted spin-echo image after cannulated screw transfixation shows normal vascularization of both femoral heads

and especially the vascularization of the femoral head was adequately assessable with contrast-enhanced MRI in each case. The sagittal 3D FFE sequences, which were acquired to assess the hip cartilage, demonstrated no signs of chondrolysis, such as loss of cartilage and joint space narrowing, in any examined hip in the postoperative MRI examinations performed within a mean time of 31.7 days. In nine children who underwent in situ fixation of the slipped epiphysis with cannulated screws and in one child who underwent open reduction of the epiphysis with subsequent cannulated screw fixation, the vascularization of the femoral head before and after surgery was normal (Fig. 2).

In a 9-year-old boy with acute and moderate SCFE, the preoperative MRI demonstrated an avascular zone in the superolateral aspect of the left epiphysis. Subsequent open reduction and internal fixation of the epiphysis with two screws was performed, and the patient presented a complete revascularization of the femoral head (Fig. 3) at postoperative MRI.

One child with severe SCFE on the left side, who underwent open reduction, corrective osteotomy through the physis, and fixation with two cannulated screws, developed an avascular necrosis of the femoral head, which was evident on the postoperative MR images (Fig. 4). One of the two inserted screws was immediately removed. However, the radiographs 8 months later showed fracture and deformation of the superolateral aspect of the femoral head due to avascular necrosis (Fig. 4). The clinical follow-up (mean time 23 months) of the children without evidence of avascular necrosis of the femoral head on the postoperative MR images was unremarkable.

Discussion

The prognosis and outcome of SCFE is related to the patient's clinical presentation, the severity of the slip, and the surgical method used for treatment [2]. The traditional clinical categories are defined as preslip, acute, acute-on-chronic, and chronic SCFE and are based on the kind and duration of symptoms. Acute SCFE is characterized by clinical symptoms—such as pain in the groin or knee, limited motion, and external rotation deformity—that last for less than 3 weeks, whereas in chronic SCFE, clinical symptoms are often present for months [2]. If additional acute symptoms and a sudden increase in the degree of the slip are noticed in patients with chronic symptoms, the disorder is classified as acute-on-chronic SCFE. In the preslip stage, a widened and irregular physis as well as mild clinical symptoms may be evident, but no slip is visible on radiographs [8].

Other authors prefer the clinical differentiation between stable and unstable SCFE, which reflects whether the patient is able to walk [9]. Another important prognostic factor in children with SCFE is the severity of slip as determined by the method of Boyer et al.: Slip angles of less than 30 degrees are graded as mild, those of 30–50 degrees as moderate, and those of more than 50 degrees as severe [10].

The most devastating complication of SCFE is avascular necrosis. In several studies, the rates of avascular necrosis were evaluated with regard to the different classifications of SCFE. Kennedy et al. identified unstable SCFE as a risk factor for the occurrence of osteonecrosis in contrast to stable SCFE [11]. In a study of 204 patients, Tokmakova et al. found no development of osteonecrosis in patients with stable SCFE, whereas in patients with unstable SCFE the risk of development of osteonecrosis increased with the severity of slip [12]. In our study, the only patient with an avascular zone on preoperative MRI suffered from acute (unstable) and moderate SCFE, and it may be speculated that the avascular zone within the slipped femoral head would have been bigger in a more severe slip.

Other factors that influence the development of avascular necrosis are reported to be reduction of the slip, pin penetration into the joint, location of pins or screws in the superolateral portion of the epiphysis, an increased number of pins or screws used for transfixation, and femoral neck

Fig. 3 A 9-year-old boy with moderate slipped capital femoral epiphysis on the left side as demonstrated by the initial radiograph (**a**). The preoperative magnetic resonance image (short tau inversion recovery) shows bone marrow edema, joint effusion, and a high signal of the epiphysis. At the superolateral aspect of the femoral head, a signal void due to avascularization is visible (**b**). After open reduction and fixation with two screws (postoperative radiograph **c**), the gadolinium-enhanced magnetic resonance image (T1-weighted spin-echo) 6 weeks after surgery reveals a complete normal signal and morphology of the femoral head (**d**)

Fig. 4 A 15-year-old boy with severe acute-on-chronic slipped capital femoral epiphysis on the left side, as demonstrated by the frog-leg plain radiograph (**a**). The preoperative magnetic resonance image (gadolinium-enhanced T1-weighted spin-echo) shows a normal vascularization of the femoral head on both sides (**b**). After open reduction and internal fixation with two screws, the gadolinium-enhanced magnetic resonance image (T1-weighted spin-echo) 4 weeks postoperatively reveals a signal void (*arrow*) due to devascularization of the cranial aspect of the femoral head (**c**). One screw was removed, but the radiograph 8 months later shows avascular necrosis with fracture and deformation of the superolateral aspect (*arrow*) of the femoral head (**d**)

osteotomy [2, 13–16]. The average overall incidence of avascular necrosis in most large series is 15% [14]. Percutaneous insertion of a single cannulated screw via a guide-pin in the central area of the femoral head is a well-accepted treatment procedure of SCFE in North America and has shown a high rate of success, a low prevalence of additional slippage, and a low complication rate [17–20]. In our study none of the patients who underwent stabilization of SCFE with a single cannulated screw developed avascular necrosis. If reduction of the SCFE is performed and two screws are placed for transfixation, the risk of avascular necrosis seems to be increased, as demonstrated by the case of a 15-year-old boy with severe acute-on-chronic SCFE in our study. In this case, the postoperative MRI allowed for early diagnosis of the vascularization deficit within the femoral head, and one screw, which was positioned in the superolateral aspect of the epiphysis, was immediately removed. Although the radiograph 8 month later demonstrated fracture and deformation of the superolateral part of the epiphysis, further damage to the femoral head was probably avoided.

MRI has not often been used for assessing SCFE. The morphologic appearance of SCFE was previously described by Daschner et al., who described widened and ill-defined epiphyseal plates on T1-weighted MR images and joint effusion and increased signal intensity in the metaphysis on T2-weighted MR images [21]. In other studies, MRI was done to evaluate preslip in the contralateral hip of children with SCFE. The MRI features of a preslip SCFE included distortion of the physis, periphyseal bone marrow edema, and joint effusion [6, 8, 22, 23]. In our MR study we observed these morphologic changes of SCFE to be most pronounced in acute and acute-on-chronic slips.

In our opinion, the main benefit of MRI in children with SCFE is the noninvasive assessment of the vascularization of the femoral heads without radiation. Maeda et al. performed selective angiography of the medial circumflex femoral artery in children with SCFE to examine whether the vascular supply is damaged before reduction of the slip [24]. With correspondence to previous MRI studies in children with Legg-Calve-Perthes disease [25–27], MRI was very effective in demonstrating the femoral head vascularization in children with SCFE in our study. A vascular deficit was clearly recognized in a 9-year-old boy with acute and moderate SCFE before surgery. Because of the MRI findings, the orthopedic surgeons chose open reduction of the slip, although the slip was only moderate. This surgical treatment may be controversial, but subsequent revascularization of the epiphysis was evident on the postoperative MR images. Without MRI, simple in situ fixation with a cannulated screw would have been performed, which might not have been sufficient to avoid avascular necrosis of the femoral head. Further studies are necessary to evaluate which surgical procedure—open reduction versus transfixation—is most sufficient for avoiding avascular necrosis in the case of a preoperatively diagnosed vascularization deficit of the femoral head in patients with SCFE.

Most reports concerning the evaluation of avascular necrosis after pinning or screw fixation of SCFE are based on postoperative radiographs and clinical follow-up examinations [12–14]. Only a few reports concern the use of early postoperative bone scan in SCFE. Fragniere et al. reported on a high sensitivity of early postoperative bone scan to detect avascular necrosis in a series of 49 children [28]. But in this report the authors also mention how delicate the interpretation of bone scans is in this pathology. MRI offers better spatial resolution than scintigraphy and has successfully been used to assess Perthes disease [25–27]. To our knowledge, postoperative MRI in SCFE has not been used so far, which may be explained by distortion of the MR images due to severe artifacts resulting from the inserted pins. In our study we observed on the postoperative MR images only minor artifacts caused by the inserted titanium screws, and the images could be interpreted accurately in each case. Furthermore, the cannulated (titanium) screw fixation of SCFE also enabled the use of gradient-echo sequences for assessing the cartilage regarding chondrolysis; however, this complication of SCFE was not observed in our patients during the follow-up period.

Conclusion

Contrast-enhanced MRI allows for accurate evaluation of the femoral head vascularization before and after cannulated screw fixation in children with SCFE. Based on the findings of preoperative MRI in children with SCFE, further studies are necessary to assess which surgical procedure is most efficient for avoiding avascular necrosis of the femoral head in the case of a detected vascularization deficit. Early detection of a postoperative loss of femoral head vascularization enables early treatment to prevent further damage to the hip joint.

References

1. Exner GU (1986) Growth and pubertal development in slipped capital femoral epiphysis: a longitudinal study. J Pediatr Orthop 6:403–409
2. Loder RT, Aronsson DD, Dobbs MB, Weinstein SL (2000) Slipped capital femoral epiphysis. J Bone Joint Surg 82:1170–1188
3. Weiner D (1996) Pathogenesis of slipped capital femoral epiphysis: current concepts. J Pediatr Orthop B 5:67–73

4. Hackenbroch MH, Kumm DA, Rutt J (2002) Dynamic screw fixation for slipped capital femoral epiphysis. Treatment results. Orthopäde 31:871–879 [German]
5. Kumm DA, Lee SH, Hackenbroch MH, Rutt J (2001) Slipped capital femoral epiphysis: a prospective study of dynamic screw fixation. Clin Orthop Relat Res 384:198–207
6. Futami T, Suzuki S, Seto Y, Kashiwagi N (2001) Sequential magnetic resonance imaging in slipped capital femoral epiphysis: assessment of preslip in the contralateral hip. J Pediatr Orthop B 10:298–303
7. Southwick WO (1967) Osteotomy through the lesser trochanter for slipped capital femoral epiphysis. J Bone Joint Surg 49:807–835
8. Lalaji A, Umans H, Schneider R, Mintz D, Liebling MS, Haramati N (2002) MRI features of confirmed "pre-slip" capital femoral epiphysis: a report of two cases. Skeletal Radiol 31:362–365
9. Loder RT, Richards BS, Shapiro PS, Reznick LR, Aronson DD (1993) Acute slipped capital femoral epiphysis: the importance of physeal stability. J Bone Joint Surg Am 75:1134–1140
10. Boyer DW, Mickelson MR, Ponseti IV (1981) Slipped capital femoral epiphysis. Long-term follow-up study of one hundred and twenty-one patients. J Bone Joint Surg Am 63:85–95
11. Kennedy JG, Hresko MT, Kasser JR, Shrock KB, Zurakowski D, Waters PM, Millis MB (2001) Osteonecrosis of the femoral head associated with slipped capital femoral epiphysis. J Pediatr Orthop 21:189–193
12. Tokmakova KP, Stanton RP, Mason DE (2003) Factors influencing the development of osteonecrosis in patients treated for slipped capital femoral epiphysis. J Bone Joint Surg Am 85:798–801
13. Rattey T, Piehl F, Wright JG (1996) Acute slipped capital femoral epiphysis. Review of outcomes and rates of avascular necrosis. J Bone Joint Surg 78:398–402
14. Peterson MD, Weiner DS, Green NE, Terry CL (1997) Acute slipped capital femoral epiphysis: the value and safety of urgent manipulative reduction. J Pediatr Orthop 17:648–654
15. Gordon JE, Abrahams MS, Dobbs MB, Luhmann SJ, Schoenecker PL (2002) Early reduction, arthrotomy, and cannulated screw fixation in unstable slipped capital femoral epiphysis treatment. J Pediatr Orthop 22:352–358
16. Reynolds RA (1999) Diagnosis and treatment of slipped capital femoral epiphysis. Curr Opin Pediatr 11:80–83
17. Aronson DD, Carlson WE (1992) Slipped capital femoral epiphysis. A prospective study of fixation with a single screw. J Bone Joint Surg Am 74:810–819
18. Goodman WW, Johnson JT, Robertson WW Jr (1996) Single screw fixation for acute and acute-on-chronic slipped capital femoral epiphysis. Clin Orthop Relat Res 322:86–90
19. Stevens DB, Short BA, Burch JM (1996) In situ fixation of the slipped capital femoral epiphysis with a single screw. J Pediatr Orthop B 5:85–89
20. Kenny P, Higgins T, Sedhom M, Dowling F, Moore DP, Fogarty EE (2003) Slipped upper femoral epiphysis. A retrospective, clinical and radiological study of fixation with a single screw. J Pediatr Orthop B 12:97–99
21. Daschner H, Lehner K, Rechl H, Heuck A (1990) Imaging of epiphyseolysis of the femur head in the magnetic resonance tomogram. Fortschr Röntgenstr RÖFO 152:583–586 [German]
22. Schittich I (2001) MRI in the diagnosis and treatment of Perthes disease and epiphysiolysis of the head of the femur. Orthopäde 30:519–527 [German]
23. Umans H, Liebling MS, Moy L, Haramati N, Macy NJ, Pritzker HA (1998) Slipped capital femoral epiphysis: a physeal lesion diagnosed by MRI, with radiographic and CT correlation. Skeletal Radiol 27:139–144
24. Maeda S, Kita A, Funayama K, Kokubun S (2001) Vascular supply to slipped capital femoral epiphysis. J Pediatr Orthop 21:664–667
25. Mahnken AH, Staatz G, Ihme N, Gunther RW (2002) MR signal intensity characteristics in Legg-Calve-Perthes disease. Value of fat-suppressed (STIR) images and contrast-enhanced T1-weighted images. Acta Radiol 43:329–335
26. Sebag G, Ducou Le Pointe H, Klein I, Maiza D, Mazda K, Bensahel H, Hassan M (1997) Dynamic gadolinium-enhanced subtraction MR imaging–a simple technique for the early diagnosis of Legg-Calve-Perthes disease: preliminary results. Pediatr Radiol 27: 216–220
27. Lamer S, Dorgeret S, Khairouni A, Mazda K, Brillet PY, Bacheville E, Bloch J, Pennecot GF, Hassan M, Sebag GH (2002) Femoral head vascularization in Legg-Calve-Perthes disease: comparison of dynamic gadolinium-enhanced subtraction MRI with bone scintigraphy. Pediatr Radiol 32:580–585
28. Fragniere B, Chotel F, Vargas Barreto B, Berard J (2001) The value of early postoperative bone scan in slipped capital femoral epiphysis. J Pediatr Orthop B 10:51–55