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Original Article

Is the femoral head dead or alive before surgery of slipped capital femoral epiphysis? Interest of perfusion Magnetic Resonance Imaging

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ABSTRACT

Background: The most common complication of slipped capital femoral epiphysis (SCFE) is avascular necrosis (AVN) of the femoral head. Surgical treatments including reduction of the femoral head are considered as a risk factor for avascular necrosis. The purpose of this study was to investigate the role of perfusion Magnetic Resonance Imaging (MRI) into the surgical decision-making sequence.

Methods: Eighteen children with 19 slipped capital femoral epiphysis were retrospectively included. SCFE was unstable in nine cases and stable in ten cases. The slip angle was higher than 60° in 14 cases. Perfusion MRI with dynamic gadolinium-enhanced subtraction sequences were done in all the cases before and after surgical treatment.

Results: On nineteen hips, eight were devascularized before surgery. All were unstable. After surgery, six on eight had a complete revascularization, one had a focal necrosis and one remained devascularized. A postoperative devascularization with normal preoperative MRI was noted once. On nineteen hips, a total of three avascular necrosis occurred.

Conclusion: Perfusion MRI is useful to assess preoperative and postoperative vascular status in SCFE. Preoperative devascularization could improve or stay equal after surgical treatment. Persistent devascularization could be responsible for avascular necrosis of the femoral head.

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1. Introduction

Slipped capital femoral epiphysis (SCFE) is the most common hip disorder affecting adolescents with a predilection for boys.¹ SCFE is characterized by a posterior displacement of the

femoral head (epiphysis) and anterior displacement of the femoral neck (metaphysis). Pathogenesis remains unclear; SCFE could be a multifactorial process resulting from biomechanical factors such as obesity, increased femoral retroversion and metabolic disorders with a relative imbalance of hormones.² Prognosis of SCFE is conditioned by the severity of

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Table 1 – Clinical presentation and severity.

Gender	
Female	4
Male	14
Age	10–16 years (mean 13.3)
Stability	
Stable	10
Unstable	9
Slip	
Mild $\leq 30^\circ$	0
Moderate $> 30 \leq 60^\circ$	5
Severe $> 60^\circ$	14

femoral head displacement and the results of surgical treatment.³ Surgery aims to reduce and stabilize the femoral head displacement to avoid further slippage and complications such as chondrolysis and avascular necrosis (AVN). Avascular necrosis of the femoral head leads to a poor functional outcome and early hip osteoarthritis.^{4,5} A lot of studies tried to identify factors influencing occurrence of AVN. Instability,^{3,5–7} surgical reduction,⁸ number and localization of pins,⁷ young age,⁵ severity of femoral head displacement⁹ were identified as risk factors but some of them are controversial. Instability and complete or partial reduction are recognized to be the most important factors influencing the risk of AVN.^{3,5} The challenge in SCFE is to get the best functional outcome with the safer surgical procedure regarding femoral head vascularization. It remains unclear whether the devascularization is due to femoral head slip itself or to surgical procedures aiming to reduce it. Gadolinium-enhanced MR imaging is a non-ionizing radiation technique that has been used to demonstrate lack of adequate blood flow in ischemic bone with a perfect histologic correlation.^{10,11} MRI with dynamic gadolinium enhanced subtraction sequences appeared to be a reliable technique for the evaluation of the femoral head vascularization in Legg Calve Perthes disease and in SCFE. This technique has a good sensitivity, high space

and contrast resolution to detect femoral head morphologic abnormalities and assess ischemia severity.^{12–15} We propose to evaluate dynamic gadolinium enhanced subtraction MRI following femoral head vascularization in SCFE requiring surgical treatment.

2. Material and methods

2.1. Patients

This study is a retrospective review of MR imaging of children who underwent MRI before and after surgery for slipped capital femoral epiphysis in our institution between 2007 and 2013. Our local ethics committee approved this study. Eighteen children: four girls and fourteen boys were included in this study. The mean age was 13.4 years (Table 1). One child had a bilateral slippage at the moment of the diagnosis so nineteen hips were evaluated, always confirmed on plain. We classified SCFE according to the clinical and radiographic findings regarding stability and severity. Stability or instability was defined as the ability or inability to bear weight on the affected hip.⁷ The severity was based on the slip angle measured on MRI axial slices (mild for slip angle lower than 30° , moderate comprised between 30° and 60° and severe higher than 60°).

The average delay between the beginning of symptoms and preoperative MRI was 4 months for stable slippage and 5 days for unstable slippage. The average delay between surgery and postoperative MRI was 17 months for stable slippage, and 13 months for unstable slippage (Table 4).

Surgical procedures were not univocal and classified according three different surgical modalities: Open reduction and internal fixation (ORIF), closed manipulation and percutaneous fixation (screwing) and in-situ percutaneous fixation (screwing). For all patients, non-weight bearing was allowed between diagnosis and surgery.

Table 2 – Vascularization before and after surgery and clinical features.

Patient	Age	Gender	Stability	Slip	Preoperative vascularization	Postoperative vascularization	AVN
1	14	M	S	68°	N	N	No
2	11	F	S	58°	N	N	No
3	13	M	U	82°	g D	H	No
4	10	M	U	76°	g D	g D	Yes
5	14	M	U	65°	g D	N	No
6	16	M	S	40°	N	N	No
7	11	M	U	75°	g D	N	No
8	13	M	S	58°	H	N	No
9	15	M	U	88°	g D	f D	Yes
10	15	M	U	61°	g D	H	No
11	16	M	S	63°	H	H	No
12	14	F	S	82°	H	N	No
13	12	M	S	86°	H	H	No
14	16	M	U	91°	H	f D	Yes
15	13	F	U	70°	g D	N	No
16	12	M	U	65°	g D	N	No
17	14	M	S	52°	H	N	No
18	12	F	S	72°	H	N	No
18 bis	12	F	S	49°	N	N	No

M: male, F: female, S: stable, U: unstable, N: normal, g D: global devascularization, f D: focal devascularization, H: hyperemia.

Table 3 – Surgical modalities and evolution of femoral head vascularization.

Surgical Modalities	Number of patients	Preoperative devascularization	Postoperative devascularization	AVN
Closed manipulation	5	4	1	1
Open reduction	11	4	2	2
Fixation in situ	3	0	0	0
Total	19	8	3	3

2.2. MR imaging protocol

MR Imaging was performed on a 1.5 T system (Achieva® 1.5 T Philips Healthcare, P.O. Box 10.000, 5680 DA Best, The Netherlands) using a magnet's body coil SENSE. MRI protocol employed coronal spin echo T1 weighted images (TR: 732 ms, TE: 18 ms, slice thickness: 4.5 mm, matrix size 512, FOV 375 mm), coronal STIR weighted images (TR: 2178 ms/TE: 160 ms, matrix size 320 × 251, FOV: 365 mm), proton density T2 weighted images in the three plans of space (TR: 278 ms/TE: 9 ms, slice thickness: 4.5 mm, matrix size 448, FOV 375 mm), axial turbo spin echo T2-weighted images (TR: 7565 ms/TE: 150 ms, slice thickness: 3.5 mm, matrix size 512, FOV 320 mm). Dynamic spin echo T1-weighted images (TR: 579 ms/TE : 12 ms, matrix size 248 × 168, FOV 250 mm, slice thickness 4 mm) was obtained at five levels in the coronal plane. After an intravenous bolus of gadolinium in a dose of 0.2 cc/kg (Dotarem® 0.5 mmol/mL, Guerbet, Immeuble Rabalais 22 avenue des Nations 93420, Villepinte, France), images were acquired in the same levels each 15 s during 3 min. Subtraction was done between post gadolinium and pre gadolinium images. Subtraction was performed using the subtraction function available as standard software on our hardware.

2.3. MRI Analysis protocol

The images were assessed retrospectively by two radiologists (HDLP and EC) whose one is a pediatric radiologist (HDLP).

On pre and postoperative MRI, femoral head vascularization was assessed on dynamic enhanced with subtraction technique images. We classified the vascularization of the femoral head as: normal, hyperemic, devascularized. In the cases of devascularization, we distinguished global and focal devascularization. Devascularization was defined as absence of enhancement on subtracted images compared with the homolateral iliac wing's enhancement. Hyperemia was defined as a more intense enhancement of the femoral head than the iliac wing.

Joint effusion, periarticular edema, disruption of the joint capsule, signs of chronicity (femoral neck buttressing, osseous metaphyseal spur formation), signal abnormalities on T2-weighted images and chondrolysis (loss of cartilage) were also noted.

Avascular necrosis was determined by radiographs showing the presence of increased density in the femoral head with total or partial collapse or by MRI showing a femoral head collapse. The minimal follow-up was one year after the surgery to detect AVN on plain radiographs.

3. Results

3.1. MRI findings and clinical outcome (Table 2)

Nine hips (47%) were unstable and ten (53%) were stable. The slippage was severe in fourteen hips (74%) and moderate in five hips (26%). No hip had a mild slippage.

Table 4 – Delays between the beginning of symptoms, preoperative MRI, surgery and postoperative MRI.

Patients	Stable/Unstable	Delay between the beginning of symptoms and preoperative MRI	Delay between preoperative MRI and surgery	Delay between surgery and postoperative MRI
1	S	2 Months	4 Days	3 Months
2	S	3 Months	15 Days	4 Years
3	U	5 Days	4 Weeks	1 Month
4	U	4 Days	3 Days	2 Months
5	U	2 Days	5 Days	6 Months
6	S	2 Months	4 Months	2 months
7	U	1 Day	9 Days	4 Years
8	S	4 Weeks	3 Weeks	4 years
9	U	3 Weeks	6 Days	5 months
10	U	3 Days	6 Days	1 month
11	S	4 Months	1 Day	3 Years
12	S	1 Year	0 Day	1 Month
13	S	6 Months	4 Days	2 Years
14	U	2 Days	7 Days	4 Years
15	U	6 Days	1 Day	2 Days
16	U	5 Days	0 Day	4 Months
17	S	1 Day	0 Day	3 Months
18	S	6 Months	3 Days	2 Months
18 bis	S	6 Months	3 Days	2 Months

Fig. 1 – A 13-year-old girl (patient 15) with an unstable SCFE. Coronal T1-weighted image (a) shows a severe slippage of the right femoral epiphysis. On dynamic sequence at 2 mn with subtraction, the femoral head had a global devascularization before surgery (arrow, b.) with a complete revascularization after surgery (arrow, c.) Anteroposterior radiograph after manipulative reduction and fixation (d) shows a good realignment of the epiphysis without AVN.

Devascularization was present on preoperative MRI in eight unstable and severely displaced hips (42%). All preoperative devascularizations were total. Among these eight hips, six had a total revascularization (75%) after surgery on postoperative MRI (Fig. 1). One remained globally devascularized and developed an AVN. One had a partial revascularization with a partial persistent devascularization, which lead to a partial AVN (Fig. 2). On postoperative MRI, only one case with an unstable and severe displacement was diagnosed with a postoperative devascularization while the head was hyperemic on the preoperative MRI (Fig. 3). This hip developed a partial AVN. At final follow-up, from 6 months to 2 years after the surgery, three patients had AVN but two of

them had preoperative ischemic femoral heads diagnosed on preoperative MRI.

3.2. Surgical technique (Table 3)

Sixteen patients (84%) underwent surgical reduction (open reduction or closed manipulation). All cases of preoperative devascularizations underwent surgical reduction (open reduction or closed manipulation), which permitted a total revascularization of the head in five cases (71%). Only one hip developed a postoperative devascularization after open reduction while the preoperative vascularization was normal. Two hips developed AVN after open reduction for one and

after closed manipulation for the other one. No hip developed AVN after pinning in situ.

3.3. Other MRI findings

In fourteen cases (74%), preoperative MRI showed joint effusion both in stable and unstable slips. No joint effusion was seen on post-operative MRI. Periarticular edema was seen in four unstable hips on preoperative MRI. Four unstable hips had a disruption of the joint on preoperative MRI.

Signs of chronicity (femoral neck buttressing, osseous metaphyseal spur formation) were noted for ten (7 stable and 3 unstable) hips on preoperative MRI. These ten hips had a typical chronic clinical history.

Fifteen hips had a T2 high-signal of the femoral head and/or neck on preoperative MRI, and only six hips still had a T2 high-signal on postoperative images. Two on eight femoral head with preoperative devascularization had a normal T2 signal. No case of chondrolysis was noted.

4. Discussions

MR Imaging is not a routine imaging in SCFE but provides some important informations. Morphologic appearances of SCFE using MRI have been previously described in literature; T1-weighted images show widened epiphyseal plate.¹⁷ Intermediate signal focal or diffuse widening of the physis

Fig. 2 – A 15-year-old boy (patient 9) with an unstable left SCFE. Anteroposterior radiograph before surgery (a) shows a severe left slippage with posterior displacement of the epiphysis and anterior displacement of the metaphysis. Coronal STIR weighted image (b) shows a severe slippage with periarticular oedema, joint effusion and high signal of femoral head and neck. Dynamic gadolinium enhanced subtraction sequences at 2 mn after gadolinium shows a global devascularization (arrow) of the left femoral head before surgery (c) and partial revascularization after surgery with persistence of a focal devascularization (arrow) (d). This hip developed avascular necrosis with loss of sphericity and collapse of femoral head (e).

circumscribed by a linear low signal margin appears to be the most sensitive sign for SCFE especially for pre slips.¹⁸ Indeed MRI is helpful in difficult diagnosis of SCFE and in early stages of pre slips.^{18–21} MRI seems to be more sensitive than radiographs and CT to detect physeal changes already present in pre slip and persistent in SCFE.¹⁸ T2-weighted images show joint effusion and increased signal intensity of the femoral head and neck.^{17,18} Joint effusion, synovitis, bone marrow edema appear to be regular features of SCFE without link with any complication.²² In our study, we also found that joint effusion and increased signal intensity of the femoral head and neck were regular, probably due to the fact that SCFE is consistent with a Salter Harris type 1 injury.

The essential contribution of MR Imaging is morphologic; it allows visualization in three different planes that is important for surgeon to evaluate the severity of the deformity especially

in the axial plane. Moreover, axial slices are well adapted for measuring slip angle.²² According Tins et al,²² MRI is more reliable to assess chronicity than clinical history. In our study all patients data with MRI “chronic” images were consistent with a clinical diagnosis of chronic SFCE. However, three clinical “chronic” histories were not documented with typical MRI chronicity images.

MRI is a non-ionizing radiation technique that allows an accurate evaluation of femoral head vascularization in SCFE.^{12,19} Dynamic gadolinium-enhanced subtraction technique has been reported to be reliable to identify ischemia in Legg-Calve-Perthes disease with high space and contrast resolution.^{13,14} Subtraction technique allows detecting the presence or absence of enhancement within epiphyseal marrow.¹⁴ In our study, this simple technique managed to show in SCFE the devascularization or the normal

Fig. 3 – A 16-year-old boy (patient 14) with an unstable left SCFE. Coronal T1-weighted image (a) and anteroposterior radiograph (b) show a severe slippage of the left femoral epiphysis. On dynamic sequences with subtraction, the femoral head was hyperaemic before surgery (black arrow, c.) however a focal devascularization with focal upper external osteonecrosis appeared after surgery (white arrow, d). Anteroposterior radiograph after surgery (e) shows an osteonecrosis with a focal upper external collapse of the left femoral head.

vascularization of the femoral head with high contrast and space resolution. Moreover, titanium screws used for internal (open or percutaneous) fixation of the femoral head were responsible of minor artifacts that made images always analyzable.

The most serious complication in SCFE is AVN because it leads to a collapse of the femoral head and early osteoarthritis, which require total hip replacement in a young population. The rate of AVN in SCFE varies in literature from 5% to 47%.¹ Zaltz et al²³ made a literature review and found a cumulative rate of osteonecrosis of 23.9% among patients with SCFE classified as unstable. In our study, we had three osteonecrosis on nine unstable hips compared to ten stable hips without any case of AVN. The interruption of blood supply is suggested to be the pathogenic factor responsible for

AVN. The femoral head is supplied with blood by the posterior superior retinacular vessels²⁴ and the physal separation during SCFE is supposed to stretch the vessels and disrupt the blood supply to the femoral head, which lead to AVN; however it remains unclear whether the devascularization occurs at the time of slipping or during surgery.^{25–28} Reduction and pins have been blamed for being responsible of vascular injury but the vascular injury appears for numerous authors to be present before surgery.^{6,7,16,29} Maeda et al²⁷ showed with super selective angiography of the medial circumflex femoral artery that three of five unstable hips had a vascular injury before surgery. One of these unstable hips had an angiography after reduction, which showed that vascular supply recovered. Our study also shows that eight unstable hips have a vascular injury with devascularization on MRI at the time of trauma,

Fig. 4 – Decision tree

before any reduction. The reduction of these slippages managed to recover the blood supply in six cases out of eight. In these eight patients, MRI proved that femoral head ischemia was due to femoral head slippage and not a consequence of its surgical treatment. Ten out of eleven normal vascularized femoral head showed on preoperative MRI remained well vascularized after surgery even with open reductions. In these cases, the normality of femoral head vascularization on preoperative MRI could be a reassuring sign regarding the final anatomical and functional outcome after surgical treatment. Devascularization of the femoral head on preoperative MRI let us believe that there's a potential risk of AVN that can not be completely avoided by a surgical reduction of femoral head displacement. Nevertheless, preoperative MRI is not predictive of the vascular outcome. Rhoad et al¹⁶ found the same result with preoperative bone scans. Five hips developed an AVN and these five hips already had an ischemia on bone scan before surgery whereas no hip without ischemia on preoperative bone scans developed AVN. However MR Imaging has some important advantages compared to bone scans: besides high space resolution with an accurate morphologic study in the three plans of space, MRI is a cross sectional imaging technique which allows to avoid projection artefacts that can be seen with bone scans.

Identify risk factors for AVN in SCFE remains difficult and controversial. Some authors consider the acuity as a risk factor⁹ whereas for other the main risk factor is femoral head instability.^{3,5–7} Tokmakova et al³ found no osteonecrosis in 204 stable slippages. We didn't find either osteonecrosis in stable slippages. Severity is also considered as a risk factor but only for unstable slippages.^{3,9,28,30}

Surgical modalities are also very controversial there are no good data supporting one approach over another. There are three objectives in SCFE surgery: avoiding further slippage, avoiding complications, having the best functional outcome.³⁰ Closed manipulative reduction and open reduction are blamed as important risk factors for femoral head devascularization^{3,4,8,30,31} but some authors estimate that open reduction are not so risky compared to the functional challenge.^{5,9,23} Some short series showed that modified Dunn procedure with femoral neck shortening and femoral head reduction and fixation seems to have a low rate of AVN with a good anatomic result.^{32–34} In-situ fixation is considered as the most safe surgical technique regarding vascularization^{30,32} but its functional result could be worse because of partial reduction of upper femoral deformity. Preoperative traction is not risky^{8,35,36} or has no real benefit.⁵ Numerous pins or screws and upper extern quadrant localization of pins or screws are also considered as risk factors.^{3,7,31} In our study, closed manipulative reduction and open reduction allowed to reestablish vascularization and avoid osteonecrosis in six cases on eight preoperative devascularizations. Two persistent postoperative devascularizations were noted after surgical reduction but these two devascularizations were already present on preoperative MRI and cleared of every wrongdoing the surgical treatment in these cases. However one devascularization appeared after surgery while this unstable hip was well vascularized before surgery. In this single case, the role of surgical procedure into femoral head ischemia needs to be taken into account.

As the devascularization occurs in unstable slippages mostly at the time of the injury, and because we noted that vascular supply could be quickly improved by surgical reduction of femoral head slippage we stress the importance that MRI should be quickly carried out in unstable forms of SCFE. For Peterson et al,²⁹ urgent reduction (less than 24 h after the diagnosis) may reduce the risk of AVN in unstable SCFE.

We think that it's important for the surgeon to know before his surgery if the femoral head is well vascularized. Moreover, it's also important to inform the family that if the femoral head is devascularized on preoperative MRI, there's a risk of a vascular necrosis that surgery can't completely avoid. In cases of postoperative devascularizations, there's a forensic interest of preoperative MRI to show that the femoral head was already devascularized and so the surgery is not responsible for postoperative devascularization.

MRI also is useful to evaluate a complex severe slippage in various anatomical planes and aims to improve surgical planning in femoral head reduction procedures.

Our results confirm that stable slipped capital femoral epiphysis have no risk of AVN and suggests to realize MRI without emergency only if severe slips to improve anatomical description and surgical planning.

We summarized the place of MRI in SFCE management in a decision tree (Fig. 4).

5. Conclusion

Dynamic gadolinium-enhanced subtraction MRI is a reliable, simple and non-ionizing radiation technique for evaluating the risk of avascular necrosis in slipped capital femoral epiphysis. Devascularization occurs at the time of injury only in unstable slippages and surgical reduction can improve the femoral head vascularization in most of the cases. We recommend to carry out MRI as soon as possible after the diagnosis to evaluate the vascularization prior surgery in unstable SFCE and without emergency in severe but stable SFCE.

Conflicts of interest

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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