Clinical Article

Avascular necrosis and chondrolysis in slipped upper femoral epiphysis:
A comparative study between multiple pin fixation with or without osteotomy and single screw fixation

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Abstract
Single screw *in situ* fixation for the management of slipped upper femoral epiphysis was introduced in 1990 and has been reported to result in a decreased incidence of avascular necrosis and chondrolysis compared to previous methods using multiple pin fixation with or without osteotomy.

To investigate this we retrospectively reviewed two groups of patients. Group A (44 patients, 55 hips) was treated over a 27-year period (1963-1989). Forty-four hips were treated with multiple pins and 11 hips had primary intra- or extracapsular osteotomy with multiple pin fixation. Group B (83 patients, 106 hips) was treated over a 7-year period (1999-2005) with single screw fixation without osteotomy. All patients were followed up for at least 2 years.

In group A avascular necrosis occurred in eight hips (14.5%); five occurred after osteotomy; two after forceful manipulation; and one was due to pinning in the posterosuperior quadrant of the femoral head. Chondrolysis occurred in 14 hips (25%), of which six (11%) were due to persistent pin penetration, and in eight (14%) chondrolysis was present at presentation (before treatment). In group B avascular necrosis occurred in only two hips (2%); both were severe, unstable slips. Chondrolysis occurred in ten hips (10%) of which two (2%) were due to persistent pin penetration, and eight (8%) had chondrolysis at presentation

We conclude that single screw fixation is a safer technique than multiple pin fixation or osteotomy. Without osteotomy avascular necrosis only occurs in severe, unstable slips. Chondrolysis due to pin penetration is almost eradicated. Chondrolysis at presentation, however, is still prevalent and occurs in female patients with severe, chronic slips.

Introduction

Slipped upper femoral epiphysis (SUFE) is notorious for its two main complications, namely avascular necrosis (AVN) of the femoral head and chondrolysis. Prior to 1990 the mainstay of treatment was multiple pin fixation with or without intra- or extracapsular osteotomy. In 1990 Morrissy[1] introduced single screw fixation and in 1992 Ward *et al*[2] showed a decreased incidence of avascular necrosis and chondrolysis with this method. This was later confirmed by other authors.[3,4]

Before 1993 AVN was thought to be due to osteotomy,[5] forceful manipulation[6] or pinning in the posterosuperior quadrant of the head interrupting the lateral epiphyseal end artery.[7] In 1993 Loder *et al* looked at 55 patients with SUFE and reclassified them as either stable or unstable.[8] Slips were considered unstable if the patient could not walk even with the aid of crutches. Patients with chronic duration slips were all stable; unstable slips were only found in acute (45%) and acute-on-chronic (76%) slips. Avascular necrosis only developed in unstable slips with an incidence of 47%.

In recent years there has been a revival of femoral neck osteotomy (with or without dislocating the hip) in moderate and severe degree slips to prevent femoroacetabular impingement.[9]

In 1980 Walters and Simon[10] showed that a pin may penetrate the joint even though it appears to be in the femoral head on antero-posterior and lateral radiographs. This persistent pin penetration can cause chondrolysis. With single screw fixation perpendicular to the growth plate and in the middle of the femoral head, persistent joint penetration should be avoided. Chondrolysis apparent at presentation, i.e. before treatment, however remains an enigma. Although most authors report a higher incidence in female patients with severe, chronic slips,[11,12] the aetiology of chondrolysis remains controversial. Some authors[13,14] propose a mechanical (decreased movement with lack of cartilage nutrition) and others an autoimmune aetiology.[15]

The aim of our retrospective study was to compare the incidence of avascular necrosis and chondrolysis in two groups of patients. One group was treated with multiple pin fixation with or without osteotomy, and the other group with single screw fixation and no osteotomy. We also assessed the incidence of AVN in relation to osteotomy in the first group and to instability and severity of slip in the second group. Chondrolysis in the first group was previously reported[16] but, in an attempt to shed further light on chondrolysis at presentation, both groups were analysed.

Although most authors report a higher incidence in female patients with severe, chronic slips, the aetiology of chondrolysis remains controversial

Patients and methods

Two groups were retrospectively reviewed. Group A (44 patients, 55 hips) was treated with multiple pin fixation with or without an osteotomy over the 27-year period from 1963 to 1989. Group B (83 patients, 106 hips) was treated over the 7-year period from 1999 to 2005, all with single screw fixation. The reason for the increased numbers in the second group was due to a consolidation of the paediatric orthopaedic services in the region in the mid-1990s.

Demographically the patient's age, sex, weight and bilateral involvement were noted. The patient was regarded as obese if the weight was above the 90th centile for age.

The duration of slip was acute if symptoms and signs were present for less than three weeks, and chronic if for three weeks or longer. In an acute-on-chronic (a-on-c) slip the symptoms (usually mild) had a duration of longer than three weeks with an acute exacerbation. Stability was classified according to Loder.[8] The slip was unstable if the patient had such severe pain that they could not walk even with crutches.

Radiographs were anteroposterior and frog lateral of the pelvis. If the slip was unstable or too painful to do a frog lateral, a rollover lateral (Judet) view was done. Slip severity was measured on the lateral radiograph (frog or rollover lateral).We used a combination of the Wilson[17] percentage slip method (*Figure 1*): mild <30%, moderate = 30-50% and severe >50%; and the Southwick[18] head shaft angle method (*Figures 2A and B*): mild <30°, moderate = 30°-60°, severe >60°.

In group A the hips were pinned with Knowles pins via open surgery. Eleven hips had osteotomies at presentation for severe slips: six were intracapsular (Dunn),[19] and five extracapsular (Southwick). In group B fixation was with a Richards 8 mm cannulated screw with a hexagonal head for easy removal (Smith & Nephew Richards Medical, Memphis, Tennessee).[20]

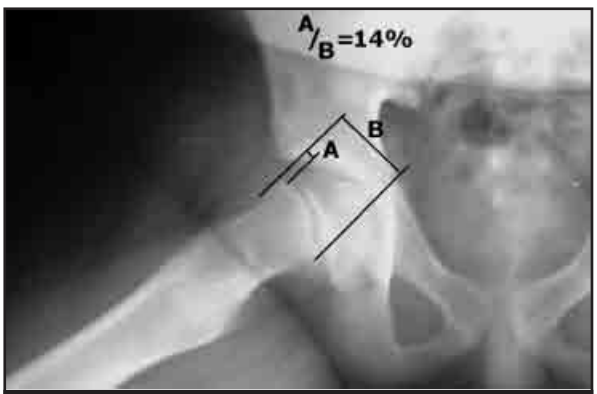

Figure 1: Frog lateral radiograph of the right hip of a 14-year-old male with a mild, chronic slip of 14% as measured by the Wilson method

Figure 2A: Frog lateral radiograph of the left hip of a 15-year-old male with a moderate, chronic slip of 50 degrees as measured by the head shaft angle of Southwick

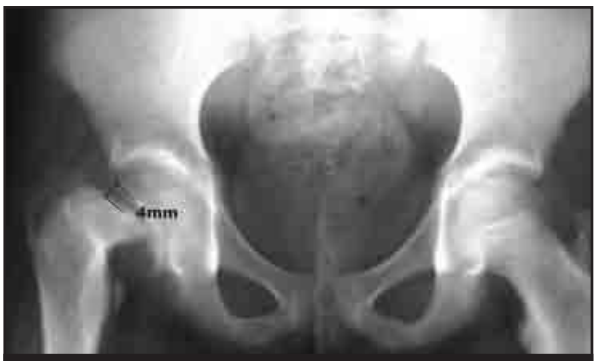

Figure 3A: Twelve-year-old female with a severe, acute unstable slip of the right hip with 4 mm anterior physeal separation regarded as unpinnable

Figure 2B: Frog lateral radiograph of the right hip of a 12-year-old female with a severe, chronic slip of 80 degrees as measured by the head shaft angle of Southwick

Figure 3B: Same patient 1 year post slow reduction and pinning with no evidence of avascular necrosis

The technique is percutaneous under image control as described by Morrissy with the screw perpendicular to the growth plate in the middle of the head. Hips were regarded as 'unpinnable' if anterior physeal separation on the frog lateral view, i.e. the distance between the anterior lip of the epiphysis and the metaphysis, exceeded 3 mm[21] (*Figures 3 and 4*). These hips were reduced with traction in abduction and internal rotation in a Thomas splint gradually over a few days as described by Casey *et al*.[6]

The patients' notes and radiographs were reviewed for features of AVN or chondrolysis. All patients were assessed for at least two years postoperatively. Chondrolysis occurs pre- or immediately postoperatively[16] and AVN should be evident by one year.[8] Chondrolysis was defined as a painful, stiff joint with joint space narrowing on radiographs of ≤3 mm, or less than half the joint space of the normal side. Pin penetration into the joint was assessed on the anterior and lateral radiograph using the Pythagorean method described by Walters and Simon.[10]

Statistical methods

The Chi-squared test was used to assess whether or not there was a significant difference in the incidence of chondrolysis due to pin penetration in the two groups and to assess the significance of the severity of the slip in chondrolysis at presentation. The Binomial test was used to assess the significance of the sex of the patients and the duration of the slip in chondrolysis at presentation.

Results

Demographics

The demographics of the two groups is similar and is shown in *Table I*. Of the total patients 27% had bilateral involvement (60% simultaneous and 40% sequentially within 18 months).

Hips were regarded as 'unpinnable' if anterior physeal separation on the frog lateral view exceeded 3 mm

Figure 4A: Thirteen-year-old female with a severe, acute-on-chronic unstable slip regarded as unpinnable

Figure 4B: Same patient 6 months post slow reduction, to original chronic position, and pinning with avascular necrosis

The average age of 12 years in girls and 14 years in boys correlates with the literature. All patients in the study were between 9 and 16 years of age and although 52% of the patients were obese, there was no aetiology for the slip. During the period of the study only two patients had a definite aetiology for the slip. One patient, 7 years old, had renal rickets and one 20-year-old had gigantism. Both were excluded from the study. The male:female ratio of 3:2 reported in the literature was reversed in our study.

Duration of slip

Two-thirds (67%) of all hips were chronic, and one-third acute or acute-on-chronic (*Table II*).

Severity of slip

Half of all slips were mild, 36% moderate and only 13% severe (*Table III*).

Avascular necrosis

In group A eight out of 55 hips developed AVN (14.5%). Five were due to osteotomies (3/6 Dunn, 2/5 Southwick), two due to manipulation and one due to pinning in the 'kill zone' (posterosuperior quadrant of the head). In group B only two out of 106 hips (2%) developed AVN and both of these were unstable (*Table IV*).

Instability and avascular necrosis

In group A the rate of instability was unknown because the sample period was before 1993 which is when Loder coined the term. In group B 20 of the 106 (19%) were unstable. No chronic slips were unstable. Eleven out of 22 acute slips and nine out of 14 acute-on-chronic slips were unstable. These figures are similar to the rates published by Loder. There were no cases of AVN in stable slips and only two of the 20 unstable slips developed AVN (10%), compared with Loder's incidence of 47% (*Table V*).

Table I: Demographics

Group A	Group B	Total
55 hips (44 patients)	106 hips (83 patients)	161 hips (127 patients)
11 (25%) bilateral	23 (28%) bilateral	34 (27%) bilateral
M 23 (52%):F 21 (48%)	M 32 (39%):F 51 (61%)	M 55 (43%):F 72 (57%)
Ave. age 13y10m (8-16)	Ave. age 13y7m (9-16)	Ave. age 13y8m (8-16)
Obese 44%	Obese 57%	Obese 52%

Table II: Duration of slip

Group A n=55		Group B n=106		Total 161 hips	
Acute	15%	Acute	23%	Acute	20%
Acute-on-chronic	11%	Acute-on-chronic	14%	Acute-on-chronic	13%
Chronic	74%	Chronic	63%	Chronic	67%

Table III: Severity of slip

Group A n=55		Group B n=106		Total 161 hips	
Mild	47%	Mild	53%	Mild	51%
Moderate	44%	Moderate	31%	Moderate	36%
Severe	9%	Severe	16%	Severe	13%

Table IV: AVN

	Total	Osteotomy	Manipulation	Pinning in kill zone
Group A	8/55 (14.5%)	5/11	2	1
Group B	2/106 (2%)	N/A	N/A	N/A

Table V: Stability

Loder's unstable slips[8]	Unstable slips in group B
Acute 17/38 (45%)	Acute 11/22 (50%)
A-on-c 13/17 (76%)	A-on-c 9/14 (64%)
AVN 47%	AVN 10%

Table VI

	Unstable hips	AVN
Total	20	2
Mild	2	0
Moderate	8	0
Severe	10 (8 'unpinnable')	2

Table VI shows the relationship between AVN, instability and severity of slip. Avascular necrosis occurred only in severe, unstable 'unpinnable' slips (*Figure 4*).

Chondrolysis

There was a six-fold decrease in chondrolysis due to persistent pin penetration in group B (*Table VII*). This is statistically significant ($p<0.05$). Chondrolysis at presentation, however, remains a significant problem (*Figure 5*).

In *Table VIII* the demographics, duration and severity of slip of all the hips (161) in the two groups are compared with the eight hips with chondrolysis due to persistent pin penetration. The distribution is similar.

In *Table IX* a similar comparison shows that the 16 hips with chondrolysis at presentation occurred exclusively in females, and significantly more likely in chronic, moderate and severe slips ($p<0.05$).

Six of the eight hips (75%) with chondrolysis due to persistent pin penetration had a good or excellent outcome after removal of the penetrating pins

The patients with chondrolysis were followed up for a minimum of 3 years. At final follow-up the hips were assessed with the Iowa hip score.[22] Six of the eight hips (75%) with chondrolysis due to persistent pin penetration had a good or excellent outcome after removal of the penetrating pins. Of the 16 hips with chondrolysis at presentation, only six (38%) had an acceptable outcome.

Discussion

Avascular necrosis and chondrolysis are disastrous sequelae of SUFE. This comparative study shows a significant decrease in chondrolysis due to persistent pin penetration with single screw fixation compared to multiple pins (2% vs 11%). Chondrolysis at presentation, however, remains an unsolved problem.

Avascular necrosis

Although avascular necrosis was also significantly reduced (14.5% vs 2%), the two groups are not entirely comparable. In group A, osteotomy was the main cause of avascular necrosis. The term unstable hip was only coined by Loder in 1993, and is currently regarded as the main cause of AVN. The hips in group A that developed AVN could have been unstable.

This study showed a much lower rate of AVN (10%) in unstable slips than that reported by Loder (47%) in 1993.[8] Reports in the literature since then reveal rates of 3% to 84% AVN in unstable slips.[23-26]

Current controversies in the management of unstable SUFE[27] relating specifically to the development of AVN, impingement and osteoarthritis are:

- whether or not to manipulate the slip
- the timing of the manipulation
- whether or not to do an immediate neck osteotomy with dislocation of the hip.

Manipulation and timing of manipulation

Traditionally manipulation, especially forced manipulation, was thought to be unsafe with a higher rate of AVN.[17,28,29] Two of the hips in group A developed AVN as a result of overzealous manipulation.

Table VII: Chondrolysis

	Group A	Group B	Total chondrolysis
Chondrolysis – pin penetration	6/55 (11%)	2/106 (2%)	8/161 (5%)
Chondrolysis – at presentation	8/55 (15%)	8/106 (8%)	16/161 (10%)

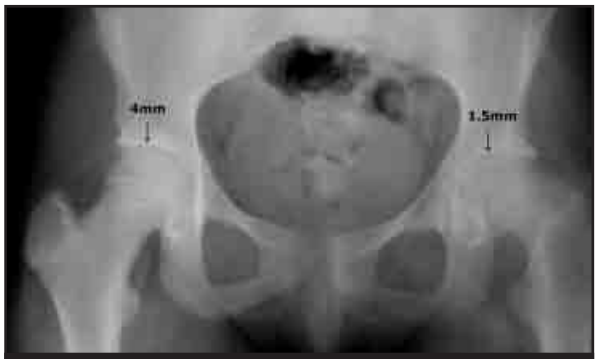

Figure 5: Anteroposterior radiograph of a 12-year-old female with a chronic severe slip of the left hip with chondrolysis at presentation

Table VIII: Chondrolysis due to persistent pin penetration vs total hips

	Chondrolysis – persistent pin penetration (n=8)	Total hips in study (n=161)
Male:Female ratio	M 3:F 5	M 55 (43%): F 72 (57%)
Average age	14y (9-16)	13y8m (8-16)
Obesity	60%	52%
Acute	25%	20%
Acute-on-chronic	25%	13%
Chronic	50%	67%
Mild	50%	51%
Moderate	50%	36%
Severe	0%	13%

Clarke and co-workers 2001[30] and 2004[31] showed no AVN with 'gentle repositioning' of moderate and severe unstable slips within 24 hours, and a 2005 survey of the POSNA members showed that 88% felt that unstable slips should be treated within eight hours.[32] This approach has been supported with angiographic studies by Maeda which showed that the blood supply can actually be restored with careful manipulation of acute or acute-on-chronic SUFE.[33] He believes that the superior retinacular branches of the medial femoral circumflex artery are damaged at the time of the slip or by manipulation that over-corrects the slip. Any manipulation therefore must not try to correct the slip to more than that which has occurred as the acute component.

Other authors however, have shown a decreased rate of AVN with slow reduction in traction.[6,8,34] We have followed this approach in 'unpinnable' hips. The 2% incidence of AVN for all the hips (10% of unstable hips) in group B compares favourably with the literature. Although it seems logical that early gentle repositioning of the femoral head to relieve pressure on the superior retinacular vessels should be the treatment of choice for unstable slips, the literature is controversial and our low incidence of AVN makes us loath to change our treatment approach. It should also be noted that serendipitous reduction, which was not assessed in this study, during placement of the patient on the traction table might not result in AVN.[35]

Neck osteotomy

In group A, three of the six hips that had a Dunn osteotomy of the femoral neck developed AVN. Dunn had a 4% incidence of AVN in chronic slips if the growth plate was open, but if the growth plate was closed a 42% incidence. In acute-on-chronic slips, 38% developed AVN.[19,36] Subsequently our unit stopped doing osteotomies and pinned all hips (except 'unpinnable' hips) *in situ*.

O'Brien and Fahey[37] felt that residual femoral neck deformity remodelled and Carney and Weinstein[29] showed a worse long-term outcome in hips after osteotomy compared to hips pinned *in situ*. Long-term studies from Sweden also showed minimal osteoarthritis of mild and moderate[38] slips pinned *in situ* and even in untreated slips.[39]

Siegel *et al*[40] showed with CT studies that the increased range of movement that occurred after the acute phase was due to decreased synovitis and not bony remodelling. Recently there has been a revival of femoral neck osteotomy. This has been driven by the Bernese school of Ganz.[9] By dislocating the hip and protecting the branches of the medial femoral circumflex artery, the femoral epiphysis can be reduced under vision and anterior interfering callus removed. They had no AVN and by accurate repositioning of the femoral head, they believe cam impingement (blocking full flexion and internal rotation) and osteoarthritis will be prevented.

We however, agree with Kay[35] that the ratio of deformity correction vs the risk of AVN with dislocation of the hip is not warranted. Our approach, compared to the current international trend (*Table X*), is to pin *in situ* (unless 'unpinnable'). If symptoms persist after one year an intertrochanteric osteotomy (Southwick[18] or Imhäuser[41]) can be performed.

Chondrolysis

Chondrolysis due to persistent pin penetration has almost been eradicated by the technique described by Morrissy using a single screw perpendicular to the growth plate and in the centre of the femoral head. The 'approach withdraw' sign, removing traction from the leg and flexing, abducting and externally rotating the hip under image should also confirm no penetration.[42] Even if joint penetration with chondrolysis does occur, there is a 75% chance of recovery if the screw is removed.

Chondrolysis at presentation

Chondrolysis at penetration, however, remains a significant problem. The aetiology remains controversial. Mankin *et al*[15] proposed an autoimmune theory. They postulated that transient pin penetration caused an autoimmune response. Our initial study of chondrolysis in 1993 however, showed radiographs (before image intensifiers) with transient pin penetration of the guidewire without subsequent chondrolysis. Also, only pins penetrating in the anterosuperior weight-bearing quadrant of the femoral head and not pins penetrating in the posteroinferior quadrant developed chondrolysis.[16]

Idiopathic chondrolysis, which was first described from our unit by Jones in 1971, also occurred in adolescents and almost exclusively in females

Table IX: Chondrolysis at presentation vs total hips

	Chondrolysis at presentation (n=16)		Total hips in study (n=161)
Male:Female ratio	M 0:F 16 (p<0.05)		M 55 (43%): F 72 (57%)
Average age	13y (11-15)		13y8m (8-16)
Obesity	56%		52%
Acute	6%		20%
Acute-on-chronic	19%	P<0.05	13%
Chronic	75%		67%
Mild	0%		51%
Moderate	50%	P<0.05	36%
Severe	50%		13%

Table X: Authors' approach vs current international trend

	Authors' approach	Current international trend
Mild or Moderate slip		
Stable	Pin *in situ*	Pin *in situ*
Unstable	Pin *in situ*	Reposition, pin *in situ*
Severe slip		
Stable	Pin *in situ*	Neck osteotomy
Unstable/ unpinnable	Slow reduction, pin *in situ*	Reposition, ± osteotomy

Our findings support the mechanical theory suggested by Waldenström[14] and Cruess.[13] The significant incidence of chondrolysis at presentation in chronic and moderate/severe slips could be due the decreased range of movement with resultant reduction of synovial fluid production compromising cartilage nutrition.

The exclusive female incidence suggests a genetic predisposition. No male with a chronic, moderate/severe slip presented with chondrolysis. It is interesting to note that idiopathic chondrolysis, which was first described from our unit by Jones in 1971, also occurred in adolescents and almost exclusively in females.[43] Previous studies[11,12] have also found a higher incidence in females, acute-on-chronic and chronic, and moderate and severe slips.

The Bernese school believes that the uncovered anterior femoral neck articulating with the acetabulum is the cause of chondrolysis and another reason to accurately reduce the femoral head.[9] However, this does not explain why chondrolysis does not occur in chronic, severe/moderate slips in male patients.

In our initial study we described a good outcome in two-thirds of hips.[16] However, we had combined the results of chondrolysis due to pin penetration with the results of chondrolysis at presentation. The results of chondrolysis at presentation are poor in two-thirds of cases, which is disappointingly similar to that of idiopathic chondrolysis.[43,44]

This study has University of Cape Town Research Ethics Committee approval REC REF 086/2007.
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No benefits of any form are to be received from a commercial party related directly or indirectly to the subject of this article.

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