

Functional Outcome and Complications after treatment of moderate to severe Slipped Upper Femoral Epiphysis with a modified Dunn procedure

by

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RESEARCH INDEX

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INTRODUCTION

Slipped Upper Femoral Epiphysis (SUFE) is defined as a displacement of the proximal femoral epiphysis by separation through the hypertrophic zone of the physis caused by low energy insult in genetically acceptable patients, and represents a devastating disease in adolescent patients.

The short term complications like avascular necrosis (AVN) and chondrolysis complicate the condition, and have a negative influence with regards to functional outcome after treatment.

The preservation of the normal or near normal anatomy and mechanical integrity of the hip joint is important with regards to normal hip biomechanics and mobility, and the varus-extension-external rotation deformity created by the slipped epiphysis results in an ineffective gait pattern with a clinically shortened, externally rotated lower limb, both with functional and cosmetic concerns.

There is wide support in the literature for treatment of SUFE with in situ pinning or screw fixation, and the advocates for this form of treatment hold the low risk for especially avascular necrosis (AVN), as well as the remodeling potential of the proximal femur, in high regard.

The question remains if the proximal femur can remodel enough to prevent the long term complication of accelerated osteoarthritis due to femoroacetabular impingement.

It is the moderate to severe, unstable slip SUFE which is at highest risk for developing AVN with or without treatment, and runs the highest risk of developing osteoarthritis later in life due to the residual deformity of the proximal femur.

Newer studies have shown that up to 40% of patients who develop early onset osteoarthritis have deformities of the proximal femur similar to those found in SUFE [1].

Subcapital osteotomies (Dunn) have the capacity to restore the normal anatomy of the proximal femur, and thus prevent femoroacetabular impingement, but because of the high risk of developing AVN, have not been accepted as standard treatment for the moderate to severe slip SUFE [2].

A review of the literature however, shows that the remodeling potential of the proximal femur is inadequate and the deformity leads to femoroacetabular impingement [3], and that the in situ pinning of the unstable, severe SUFE has a risk of AVN up to 40% [4].

It stands to reason that, if we can find a way to **safely** restore the normal anatomy of the proximal femur, we might have found a way in which to confidently manage the moderate to severe, unstable SUFE.

The modified Dunn procedure combines a subcapital realignment osteotomy with a surgical dislocation of the hip technique that specifically protect the tenuous blood supply to the femoral head, thereby diminishing the risk of AVN in the unstable, moderate to severe SUFE.

The pioneering publication with regards to the modified Dunn technique was published in 2009 and included results from two institutions, who utilized this technique since 1998 and 2001 respectively.

After familiarizing themselves with the technique, this operation was performed by two Paediatric Orthopaedic Surgeons from the Lady Michaelis Unit at Tygerberg Hospital since January 2006.

The pioneering team had near perfect radiological reduction, with no major complications, and a good functional outcome as evaluated by Harris and WOMAC scores, on all patients published in their series.

The aim of this study is to evaluate the reproducibility of these results in a group of South African adolescents with unstable, moderate to severe SUFE treated with a modified Dunn procedure, and comparing our findings with regards to amount of reduction achieved, functional outcome based on the Harris and WOMAC scores, and post operative complications, with those of the pilot study.

The long term complication of osteoarthritis will not be evaluated in this study, but we believe that the theoretical advantage of performing a subcapital realignment procedure at the CORA (Centre Of Rotational Angulation) of the deformity, can restore near normal hip anatomy and mechanics, prevent impingement, and therefore limit the development of early onset osteoarthritis.

LITERATURE REVIEW

1. Incidence:

Slipped upper femoral epiphysis (SUFE) is a condition characterized by separation of the femoral epiphysis through the hypertrophic zone of the proximal physis.

The incidence of SUFE is in the range of 3/100000 in the Caucasian population and up to 7/100000 in the Black population [5].

The mean age distribution in males is 12-14 years, and in females 10-13 years [5].

Predisposing factors include obesity, rapid growth and endocrinopathies.

A left sided slip is more common than right, and bilateral slippage occurs in up to 20% of cases. This incidence rise up to 60% in patients with known endocrinopathies including hypothyroidism, renal rickets, pituitary deficiency and growth hormone deficiency, especially in those treated with exogenous growth hormone [5].

2. Aetiological factors:

Mechanical risk factors include a reduction in femoral anteversion. The importance of this is emphasized when you consider that a 10 degree reduction in anteversion will lead to a 20% increase in shear forces over the physis. Load to failure of the physis is 3-4 times body weight, and this can be experienced during normal activities [6,7].

Maturation factors dictate a narrow skeletal age range, with young patients being more mature and older patients being borderline immature. In girls, SUFE occurs almost exclusively before the menarch [8].

Ultrastructural changes include disorganized arrangement of the columnar cells in the hypertrophic zone of the physis. In SUFE the slip occurs in this zone whereas the physal separation in Salter Harris fractures occurs between the hypertrophic zone and the zone of calcification [9].

Endocrine abnormalities may lead to a 60% incidence of bilateral slippage at initial presentation, and may represent an imbalance between Growth Hormone (causing physal hypertrophy), and Gonadal Hormones (stimulate physal closure) [10].

3. Clinical evaluation:

Pain, limping, and decreased range of motion in a peripubertal child are highly suggestive of SUFE.

However, up to 50% of patients have no pain, and in 23-46% of patients the pain is localized to the knee, and not the hip, which leads to a delay in diagnosis and even unnecessary knee arthroscopy prior to diagnosis [11].

Age and symptom duration are important, in that older children with longer duration of symptoms present with a more severe slip [12].

The older method of classification, using time of presentation as a guide, namely pre-slip, acute, chronic and acute on chronic slip, has made way for a newer method as described by Loder et al. This classification relies on the **inability** to bear weight and the presence of an effusion on sonar to distinguish the unstable from the stable slip. In the stable slip the patient **can** bear weight and an effusion in the hip joint is absent, and vice versa for the unstable slip [13].

In the unstable slip the epiphysis moves independently, which leads to intra-articular irritation and effusion [13].

Identifying the unstable slip has a dual function: Identifying the patient at high risk of developing osteonecrosis of the femoral head caused by a decrease of blood supply to the femoral epiphysis secondary to the pressure effect of the effusion and to guide emergency treatment in the form of open reduction of the femoral epiphysis.

Stability at presentation: ([Loder et al](#)) [13]

	Stable SUFE	Unstable SUFE
	= Weight bearing is possible	= Weight bearing not possible
Severity of slip	Less severe	More severe
Effusion (Ultrasound)	Absent	Present
Good prognosis	96%	47%
AVN	0%	50%

4. Blood supply to the femoral epiphysis:

The main blood supply to the femoral epiphysis comes from the deep branch of the medial femoral circumflex artery. This artery lies just superior and posterior to the lesser trochanter and is at risk of iatrogenic damage when performing open reduction for an unstable, moderate to severe slipped upper femoral epiphysis [14].

Contribution from the foveolar artery in the ligamentum teres is not an important source of blood supply to the femoral head [14].

The risk of AVN to the femoral head increases with manipulation, over reduction and inappropriate pin placement, whereby protrusion through the posterior cortex of the femoral neck can damage the already precocious blood supply to the femoral head [15].

AVN is caused primarily by disruption of the blood supply during the initial slip, as well as from the secondary pressure effect caused by the effusion present in the unstable slip SUFE, as described by Loder et al. Incorrect pin placement is another possible cause of AVN. All of the above is thus more prevalent in the unstable SUFE [15].

A tense effusion in the unstable slip SUFE therefore requires timely reduction [16] to limit the already high risk for AVN, compared to the stable slip which can be managed semi-electively because of the relative low risk for AVN [15].

5. Radiological evaluation:

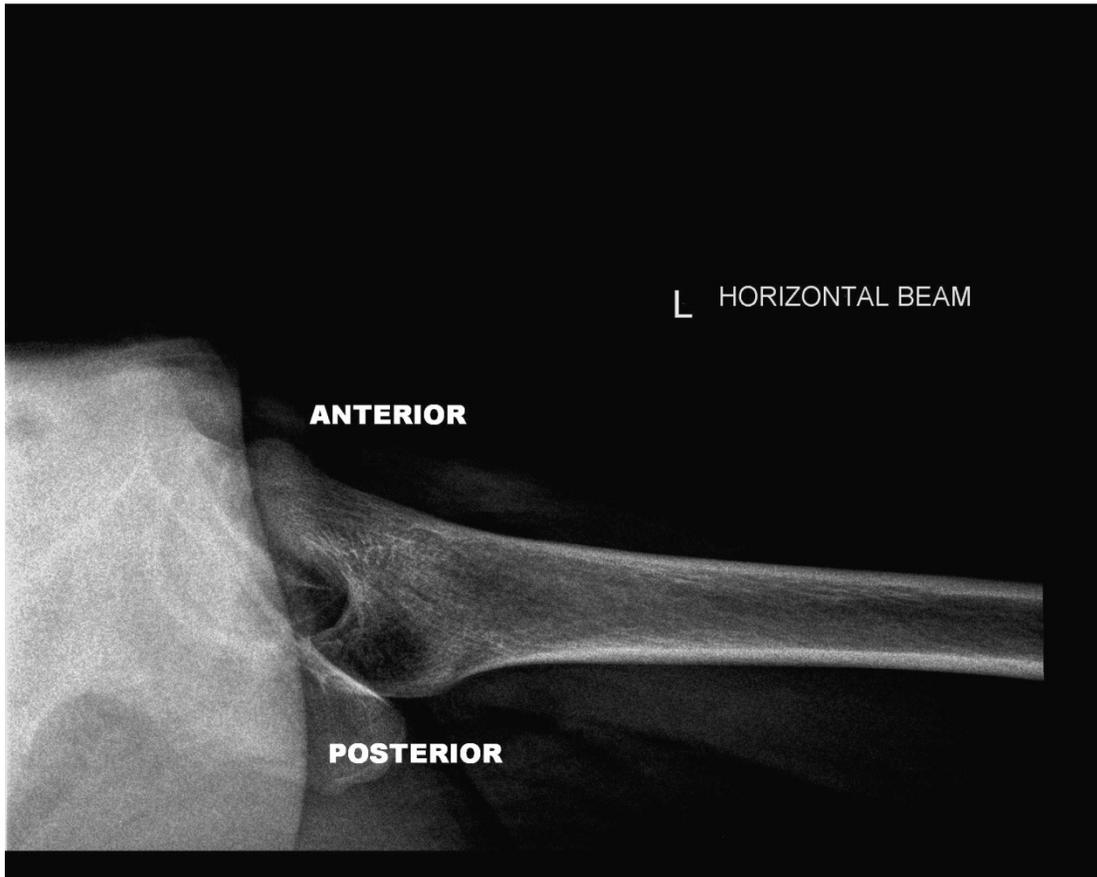
Standard Radiography i.e. AP (Antero-posterior) and lateral x-rays of both hips are usually all that is needed for the diagnosis of SUFE.

In a stable slip the standard x-rays to request would be AP pelvis and frog leg lateral x-rays, but in a potentially unstable situation care should be taken not to exacerbate the slip by placing the limb in the frog leg position, and in this situation a shoot through lateral may be the safer option.

A frog leg lateral view would also be inaccurate in the presence of pain or spasm of the affected hip [17].

A frog leg lateral is not only useful in the diagnosis of SUFE, but through measurement of the lateral Southwick angle a comparison of pre- and post operative reduction can be made, thereby evaluating the accuracy of reduction achieved by a subcapital realignment technique.

Fig 1: Lateral view of a moderate SUFE with displacement of the epiphysis in a postero-inferior direction.



Most of the changes seen on plain x-ray are due to mal positioning of the femoral epiphysis, and include the following:

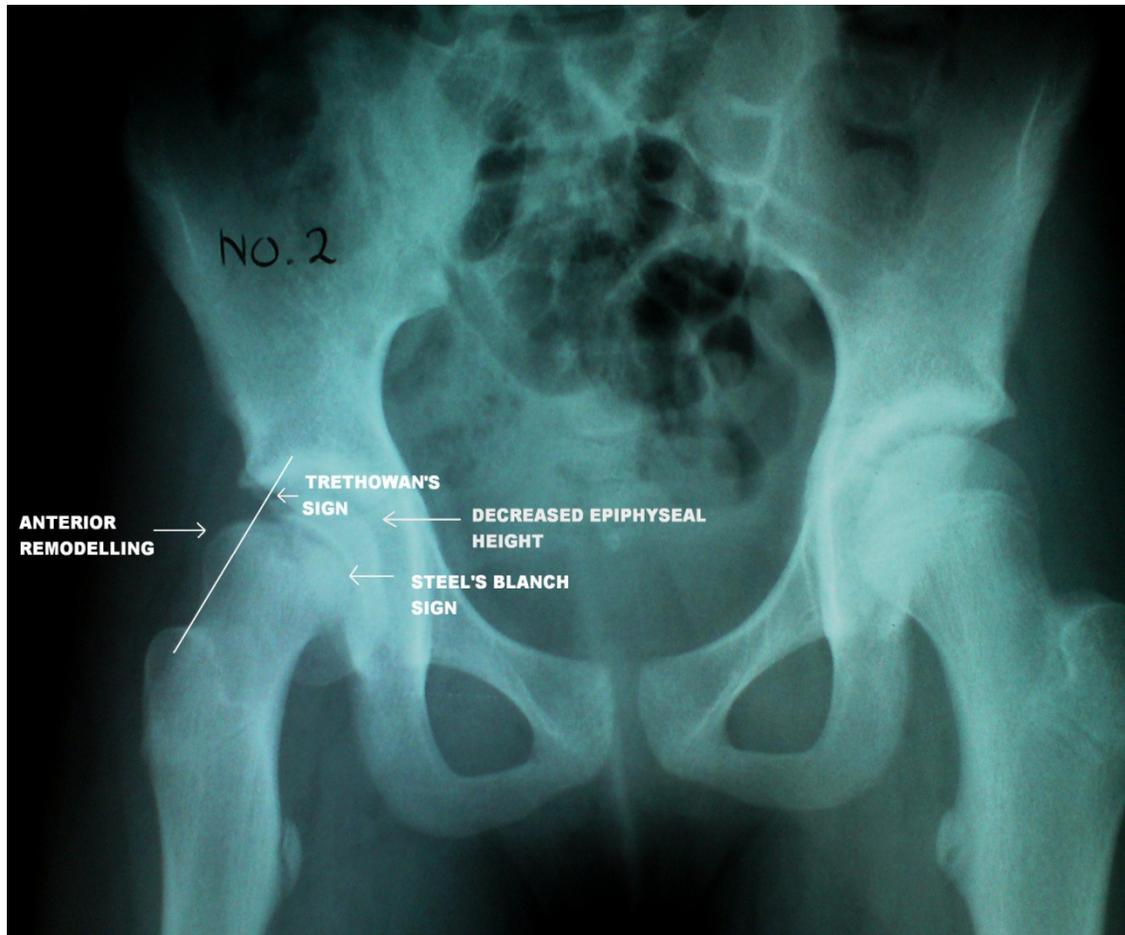
A widened physis (pre-slip) and decreased epiphyseal height.

A line drawn along the superior cortex of the femoral neck (Klein's line) does not pass through the epiphysis = **Trethowan's sign** [18].

Steel's metaphyseal blanch sign is caused by overlap of the epiphysis and metaphysis, and can be seen as a crescent shaped density that lies over the metaphysis adjacent to the physis [19].

A chronic slip is indicated by anterior metaphyseal remodelling of the proximal femur.

Fig 2: The radiological signs seen in SUFE.



The severity of the slip correlates with the amount of displacement of the epiphysis, measured in thirds of the total width of femoral neck, as described by Wilson [20], and with the angle of displacement (head-shaft angle of Southwick), as measured on a lateral x-ray of the hip [21].

The normal values according to Southwick are 10 degrees posterior on the lateral, and 145 degrees when measured on the antero-posterior (AP) view [21].

<u>Grade</u>	<u>Severity of slip</u>	<u>Slip / Displacement</u>	<u>Slip angle (Southwick)</u>
I	Mild	< 1/3	< 30° from Normal
I	Moderate	< 2/3	30°-60°
III	Severe	>2/3	>60°

Fig 3: Southwick angle as measured on an antero-posterior and lateral view x-ray respectively.

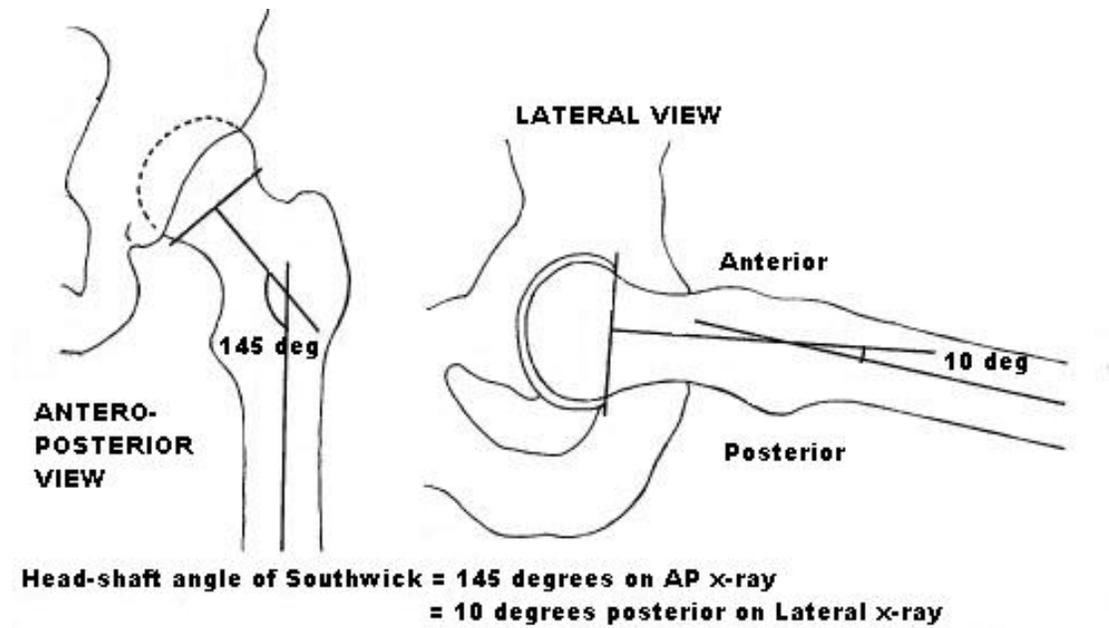
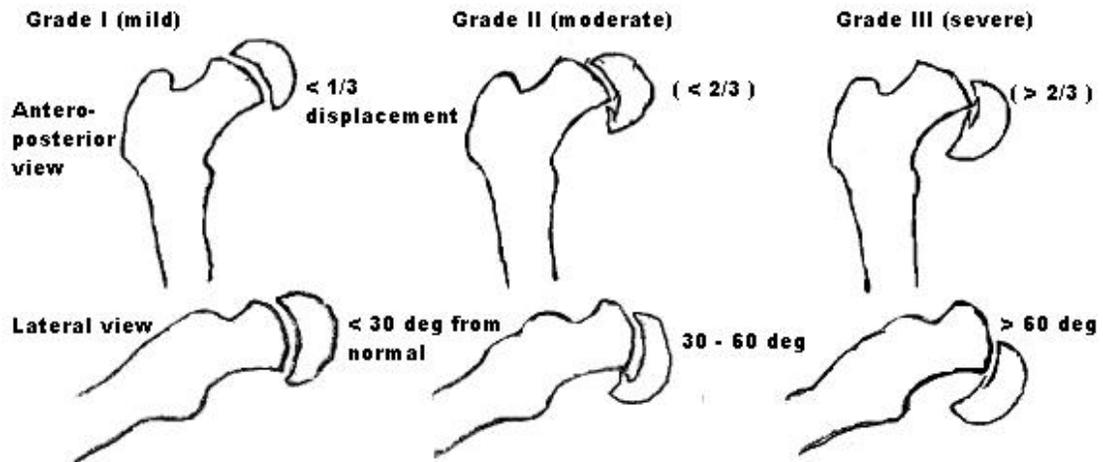


Fig 4: SUFE grade can be expressed as the amount of displacement of the epiphysis on the femoral neck measured in thirds, or the amount of deviation in the lateral Southwick angle from normal.



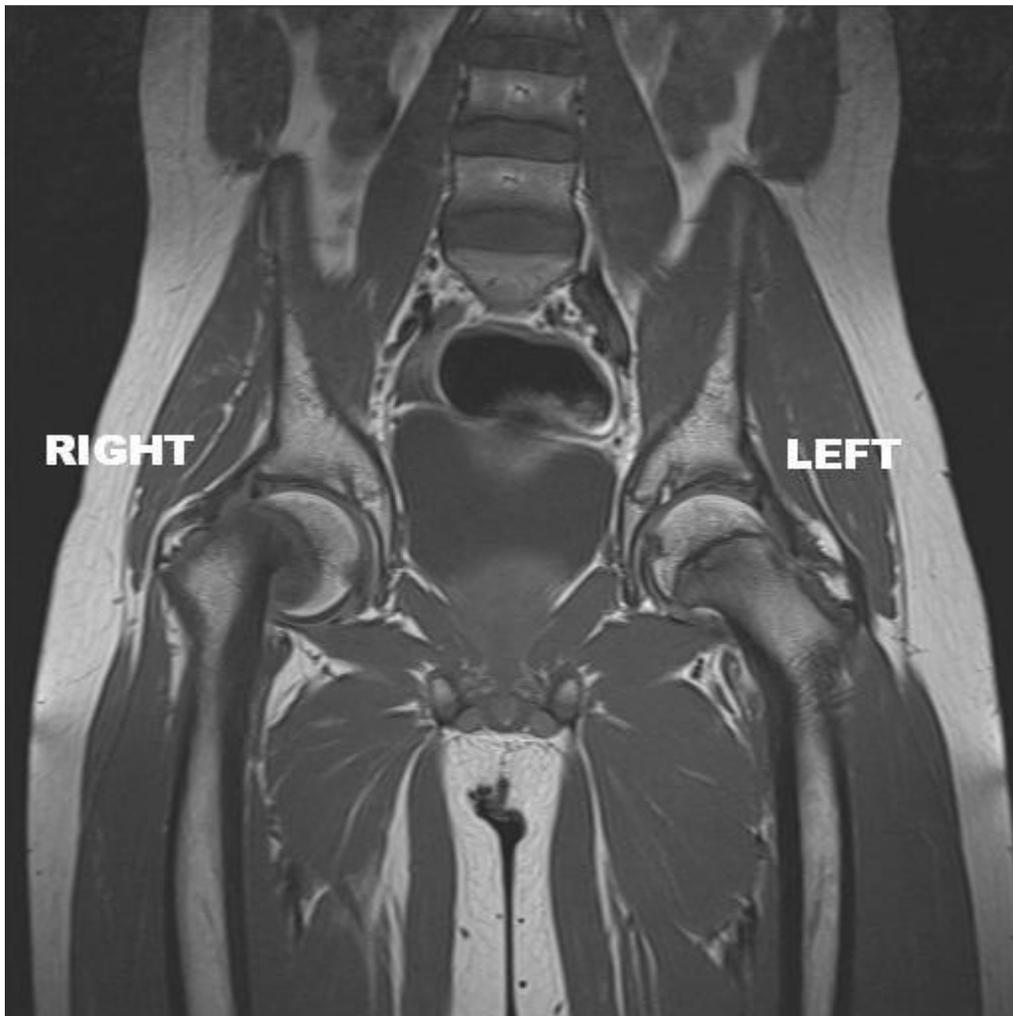
Other helpful imaging modalities include Magnetic Resonance Imaging (MRI), which can detect early signs of AVN, and technetium bone scanning (Tc 99), which can identify a pre-slip and detect AVN.

MRI can diagnose a pre-slip, but there is no evidence to support the fact that it can not be detected on plain films [22].

Serial ultrasound is helpful in detecting physal displacement and to identify an effusion associated with the unstable SUFE [23].

CT scanning is of little value in the radiological evaluation of SUFE, and plays a more important role in the pre-operative assessment, prior to corrective osteotomy in the chronically slipped epiphysis [22].

Fig 5: MRI showing SUFE, but no signs of AVN in the right hip of this patient.



6. Treatment:

Spica treatment:

Not recommended, as it leads to pressure sores, chondrolysis, and further slippage once the spica is removed ([Meier et al. JBJS 1992. 74A: 1522-9](#)).

In situ pinning:

Advocated for mild to moderate (grade I/II) SUFE, which forces the physis to fuse, thereby preventing further slippage of the epiphysis.

The entry point is usually on the anterior aspect of the femoral neck, and should be aimed at the centre of the epiphysis on both antero-posterior and lateral views, and should be positioned 5mm or more from the joint surface to prevent pin penetration into the joint, with resultant chondrolysis [24].

The superolateral corner of the proximal femur should be avoided so as not to cause damage to the artery of Brodetti with resultant AVN [25].

Single screw fixation leads to less chance for pin penetration and chondrolysis, compared to multiple screw fixations [26].

Fixation with a second screw leads to a 33% increase in resistance to shear forces, but increases the complication rate 10 fold [27].

Transient pin penetration does not cause chondrolysis ([Zionis et al. JBJS \(A\) 1991](#)).

There is some controversy surrounding the prophylactic pinning of the contra lateral side, but it is generally accepted that the unaffected side be treated if any pain is present or develop, any endocrinopathies are present, and with young age at presentation [24].

It should be mentioned that patients that are not able to follow up readily due to social or financial constraints, should also be considered for prophylactic pinning.

Controversy exists with regards to pin removal, and the literature neither support nor refute it, but it is generally accepted that the complications outweigh the advantages, and therefore routine removal is not advocated [27].

Bone graft epiphysiodesis:

After surgical exposure of the proximal femur a window is cut into the anterior cortex of the femoral neck. Using a hollow core drill and curette a trough of bone extending from the metaphysis across the physis and into the epiphysis is removed. Corticocancellous graft from the iliac is then inserted into the graft bed thereby facilitating fusion across the proximal femoral physis

This procedure has as a high complication rate, including AVN, chondrolysis, and heterotopic ossification, and is therefore generally not performed [20].

Osteotomies:

Used to correct the extension, varus, and rotational deformities associated with severe SUFE.

In moderate and severe SUFE, realignment procedures have been described for the intertrochanteric (Southwick) [28], basicervical (Kramer) [29] and subcapital (Dunn) [30] levels, each with its own set of risk factors for future morbidity and complications.

In situ pinning for stable SUFE carries a very low risk for AVN, compared to osteotomies, in which the risk for AVN is almost reciprocally proportional to the distance from the physis at which the osteotomy is performed [31,32,33], with subcapital realignment procedures (Dunn's osteotomy) carrying a risk for developing AVN ranging from 10% to 100% [34,35,36].

The risk for developing the combination of osteonecrosis and chondrolysis is up to 42% with subcapital osteotomies [34,35].

Basicervical osteotomies (Kramer): [29]

These technically demanding, extra capsular, biplanar osteotomies can be used to correct the deformity caused by severe SUFE in cases in which the physis is closed, and result in near normal anatomy, but can only correct up to 50 degrees of slippage [35,37].

Intertrochanteric osteotomies (Southwick): [28]

This osteotomy is a tri-planar osteotomy incorporating valgus, flexion and internal rotation, and is generally performed after closure of the physis.

It carries a lower risk of AVN, but the biplanar wedge resection cannot correct a slip angle of more than 60 degrees, and has the added risks of developing chondrolysis and complicating future total joint arthroplasty [28].

Subcapital osteotomies (Dunn): [30]

Despite the increased risk of complications, a subcapital osteotomy done at the level of the deformity, can correct any degree of slip angle and restore normal anatomy, without clinical loss of length to the femur [2].

An added theoretical advantage over other techniques is that by restoring normal hip anatomy and function, the long term complication of osteoarthritis can be limited through prevention of femoroacetabular impingement.

Although remodelling of the proximal femur does take place through absorption of bone adjacent to the physis at the anterosuperior margin, and deposition of bone at the posteroinferior margin, this has little effect on the femoral head/neck relationship, as seen with in situ fixation of moderate to severe SUFE [38].

Stulberg et al found that in up to 40% of patients with osteoarthritis, a similar proximal femoral deformity was found than in those patients treated for SUFE at a young age, which leads to believe that the “Pistol grip” deformity causes femoroacetabular impingement, which in turn can lead to early onset osteoarthritis [3].

Follow up shows that osteoarthritis can develop in moderate SUFE without complications, and that probably up to 10% of SUFE develop osteoarthritis.

Femoroacetabular impingement (cam impingement) is seen after remodelling of SUFE fixated in situ, and can lead to early secondary osteoarthritis.

If we can therefore find a way to limit the short term complications of AVN, chondrolysis and functional loss, and decreasing the morbidity of early onset osteoarthritis by restoring normal hip anatomy and mechanics, we have found a way to effectively manage moderate to severe unstable SUFE.

Due to the above concerns the modified Dunn procedure [39] has been developed. This technique combines a surgical dislocation of the hip (Ganz) [40], with a subcapital realignment procedure, thereby limiting the devastating complication of AVN.

Modified Dunn Procedure: [39,40]

This procedure employs a surgical dislocation technique, which allows the development of an extended retinacular soft tissue flap as described by Ganz [40], combined with a subcapital realignment procedure as described by Dunn [39].

The combination allows extensive subperiosteal exposure of the femoral neck, which allows trimming of the femoral neck and thus safe reduction of the femoral head.

Through the surgical dislocation technique the vulnerable posterior blood supply to the femoral head is preserved. This technique also allows for intra-operative evaluation of epiphyseal blood flow, either through laser Doppler flowmetry, or by simply drilling a 2mm hole into the epiphysis and observing pulsating cancellous bleeding [40].

During capital reorientation the tension on the posterosuperior capsule is further reduced by cuneiform wedge resection of varying size and location, thereby preserving the end branches of the medial circumflex artery [39].

Accelerated fusion and revascularization of the epiphysis is accomplished by removing the remainder of the growth plate [39].

The unstable SUFE is the main indicator for this procedure, because through direct visualization of the femoral blood supply, and careful dissection of the periosteum around the femoral neck, the risk for developing AVN can be limited [39].

An unstable physis facilitates a mobile epiphysis, and is thus suited for capital reduction. In the stable SUFE intraoperative evaluation of physeal instability is important, because a surprising number of stable SUFE has mobile physis which can be realigned. Intertrochanteric realignment procedures should be used if the physis is immobile, because of the increased risk of AVN when attempting capital realignment with a stable physis [39].

This technique is thus best suited for moderate to severe unstable SUFE, and requires a full understanding of the vascular anatomy of the hip.

Although this procedure is technically demanding, it restores the normal anatomy of the hip, which in theory should lead to good long-term results.

7. Complications:

In a study by Ziebart and Ganz [39], 40 patients were reviewed on whom the modified Dunn capital realignment was performed, and none of these patients developed AVN, deep vein thrombosis, infection or heterotopic ossification as short term complications.

From these findings, together with the theoretical advantage of preventing the late complication of osteoarthritis through anatomical reduction and mechanical restoration of the hip joint, we might have found a relatively safe and effective method of managing the moderate to severe unstable SUFE.

Avascular necrosis (AVN)

Causes include injury to the vessels during the initial incident, severity of the slip grade, manipulation of the unstable slip, effusion with secondary pressure effect as seen in unstable SUFE, over reduction, iatrogenic through inappropriate pin placement, and not performing a timely reduction in the unstable SUFE [15].

Osteonecrosis of the femoral epiphysis in stable SUFE is rare after treatment with pinning in situ [31,41].

Realignment procedures through osteotomies carry the highest risk for AVN, with an increase in the incidence of AVN the closer the osteotomy is performed to the physis [31,32,33].

It thus dictates that a subcapital realignment procedure, although restoring near normal anatomy and offers the best chance of correcting the anatomic deformities that can lead to early osteoarthritis, carries with it the highest risk for developing AVN.

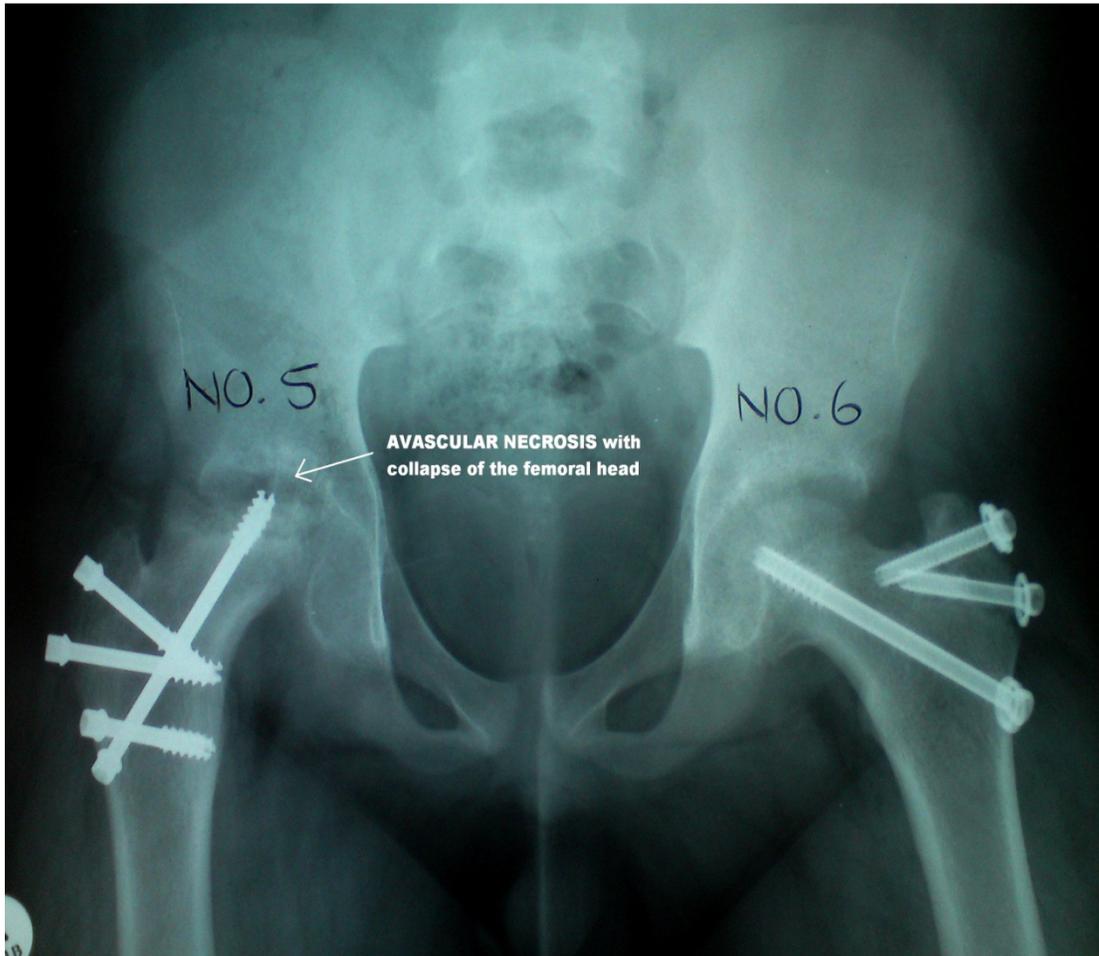
Despite relieving retinacular tension through metaphyseal wedge resection and removing the remainder of the physis to facilitate neovascularization, osteonecrosis still occurs in 10% to 100% during subcapital realignment through an open technique [34,35,36].

AVN during in situ pinning for moderate to severe unstable SUFE ranges from 10% to 40% [4].

However, the study by Ziebart and Ganz [39] published in 2009, reviewed 40 patients from two centers with unstable SUFE treated with a modified Dunn procedure. They combine the surgical dislocation technique of Ganz with subcapital realignment as described by Dunn and surprisingly found the incidence of AVN much lower in that no patient developed AVN as a direct cause of the procedure, while achieving near perfect reduction.

If these results could be duplicated in other studies, the unstable moderate to severe SUFE can be managed with little to no short and long term morbidity.

Fig 6: X-ray showing AVN and collapse of the femoral head on the right. This patient had signs of AVN on pre-operative imaging (MRI/bone scan), as well as **no** pulse trace, suggestive of blood flow to the epiphysis, intra-operatively.



Chondrolysis: [42]

Chondrolysis in SUFE represents damage to the articular cartilage caused by a traumatic event such as pin penetration across the joint or secondary to the slip itself, and is diagnosed by joint space narrowing and decreased range of motion of the affected hip.

Chondrolysis at presentation shows a possible genetic predisposition in black and coloured females, with an incidence of 44% and 33% respectively, according to a study done by Vrettos and Hofmann [42].

Transient pin penetration does not cause chondrolysis, whereas persistent pin penetration in the weight-bearing portion of the joint (anterosuperior) is synonymous with the development of chondrolysis [42].

Patients with pin penetration in the non-weight bearing portion of the bone seldom develop chondrolysis, which favours a mechanical rather than autoimmune cause for chondrolysis.

Immobilization as a cause for chondrolysis is well established as seen during spica casting (Lowe 1961), heavy traction (Lowe 1961) and Southwick's osteotomy (FryMoyer 1974), all which have a common denominator namely immobilization.

Pin penetration in the weight-bearing portion of the bone has a similar effect due to immobilization secondary to pain.

Decreased joint motion causes a decrease in synovial fluid production, which impairs cartilage nutrition and promotes chondrolysis (Waldenstrom 1930, Cruess 1963).

A greater degree of slip at presentation in turn causes restricted range of motion, which promotes chondrolysis by before mentioned paths.

Removal of the penetrating pin results in improvement in the pain as well as an increased range of motion.

Maximum joint space narrowing occurs within the first year, and there is no relation between the amount of joint space narrowing and range of motion [42].

Improvement in the joint space and range of motion can be expected up to three years after maximal involvement, and long-term review shows an almost complete reduction in pain, but in some patients residual stiffness persists [42].

Fig 7: Chondrolysis developed in this patient, as seen by the decreased joint space and sclerosis coupled with a decreased range of motion.



Osteoarthritis:

According to a study done by Carney, Weinstein and Noble, in which they reviewed the long term outcome in 155 SUFE patients, they found a direct correlation between the severity of the slip and short term complications like chondrolysis and osteonecrosis [43].

Realignment procedures were also found to increase the risk for AVN/chondrolysis, as well as having an adverse effect on long term outcome with regards to the development of osteoarthritis [43].

They found that in situ pinning provided the best long-term result with regards to delaying the development of osteoarthritis, irrespective of the severity of the slip [43].

In contrast to the before mentioned study, Murray reviewed 200 hips in patients with idiopathic osteoarthritis, and found that in up to 40% of these patients a deformity of the proximal femur, similar to that found in SUFE, was present [1].

His findings were supported by the study done by Stulberg et al which leads to the conclusion that although remodelling of the proximal femur does take place in the moderate to severe slip SUFE, it is not enough, and this deformity leads to degenerative osteoarthritis through femoroacetabular impingement [3].

Reduction of the head/shaft angle to near normal, thereby restoring normal hip biomechanics, has the theoretical advantage of delaying or even preventing late degenerative osteoarthritis.

The modified Dunn procedure [39] allows us this option by not only achieving save reduction of the epiphysis, but by employing a surgical dislocation technique [40] that reduces the short term complications of AVN and chondrolysis in the unstable moderate to severe SUFE.

Symptom duration is associated with cartilage damage, which poses the question if osteoarthritis can really be prevented in the SUFE of long-term duration, after capital realignment [43].

In a study by Ziebart and Ganz published in 2009 (Clinical Orthopaedics and Related Research) [39], they reviewed 40 patients on whom the modified Dunn capital realignment was done, and had no incidence of AVN, deep vein thrombosis, infection, heterotopic ossification, screw breakage or loss of fixation, or early chondrolysis as short term complications.

From these findings, together with the theoretical advantage of delaying the late complication of osteoarthritis by anatomical reduction and mechanical restoration of the hip joint, a method of managing this complex problem might have been found, should these results be reproducible.

Complications after pin/screw fixation: [[Riley et al. JBJS 1990. 72A:1500-9](#)].

The authors reviewed 202 (308 hips) SUFE patients fixated with either pins or screws, and found a 26% serious complication rate directly related to the method of fixation.

The total percentage of complications after pin/screw fixation was 40%, with 18% of the patients in need of a second procedure to correct a pin related complication.

Table 1: Percentage of complications after pin/screw fixation found in a review done by Riley et al.

Pin penetration	13%
avascular necrosis	5%
Chondrolysis	3%
screw breakage	3%
fracture	0.3%
infection	0.3%
further slippage	0.3%
sciatic-nerve injury	0.3%

8. Functional outcome: Restoration of the head/shaft angle and hip range of motion

One of the selling points of subcapital realignment is the near anatomic reduction and increased range of motion of the affected hip, thereby theoretically decreasing the future risk of osteoarthritis [39].

To substantiate this claim a comparison has to be made between the post operative evaluation of patients treated by subcapital realignment (modified Dunn), versus treatment with more traditional methods (in situ pinning).

A **study** done by Siegel and Kasser, published in 1991 in the Journal of Bone and Joint surgery, evaluated the post operative correction in the head/shaft angle, as well as post operative range of motion, in 45 patients (56 hips) with SUFE treated **with in situ pinning**: [38]

Of these patients 12 hips had a slip angle of more than 60 degrees.

Their result showed a mean lateral slip angle of 41.0 degrees (21-84) improves to 37 degrees (18-82) with a mean range of motion of 118 degrees flexion, 11 degrees internal rotation and 52 degrees external rotation (in flexion) respectively.

The mean range of motion for SUFE with more than 60 degrees lateral slip angle was 115 degrees flexion, 11 degrees internal rotation with hip flexed and 49 degrees of external rotation with hip flexed.

A **study** done on the treatment of moderate to severe SUFE treated by a **modified Dunn procedure** [39] showed a mean lateral slip angle of 56.6 degrees improve to 8.6 degrees.

They showed a mean postoperative range of motion of 104 degrees flexion, 29 degrees internal rotation and 43 degrees external rotation in flexion respectively.

We can thus see a marked improvement in epiphyseal reduction and internal rotation with employment of the modified Dunn procedure, while achieving comparative results in flexion and external rotation when compared with in situ pinning.

Fig 8: Subcapital realignment has the potential to restore near normal hip anatomy and mechanics, thereby facilitating an improvement in hip range of motion and limiting femoroacetabular impingement.



9. Conclusion:

From the literature review we can conclude that a modified Dunn capital realignment procedure can achieve a near anatomic reduction of the femoral physis, lead to increased range of motion, especially internal rotation in flexion, and theoretically reduce future osteoarthritis by preventing femoroacetabular impingement.

It does however theoretically pose a significant risk for short-term complications like AVN, chondrolysis and postoperative stiffness, although none of these complications were present in a retrospective review from

MATERIALS AND METHODS

This study is a retrospective review of the medical records and radiological reduction achieved, in patients treated with a modified Dunn procedure for moderate to severe SUFE, at Tygerberg Hospital, Cape Town.

The procedure was performed at this institution since 2006, and includes eight hips (seven patients).

Inclusion criteria were all patients with moderate to severe SUFE which we deemed unpinnable, and included both male and female patients from different ethnical groups.

Stable SUFE was not excluded in the study, due to the fact that a high number of stable SUFE still had a mobile physis intra-operatively which was amendable to treatment with a modified Dunn procedure [39].

Exclusion criteria included hips with pre- and intraoperative confirmation of avascular necrosis. These patients were included in the evaluation of reduction achieved radiologically, but excluded in the evaluation of range of motion and functional outcome scoring systems.

Prior to commencing this study, Ethical Committee approval, as well as approval from the institution at which the study was performed, was obtained.

The statistical analysis and validity of the study was determined in consultation with the Centre for Statistical Consultation at the University of Stellenbosch.

Data was collected and compiled by the principal investigator and the results confirmed by the supervisor overseeing the study.

No patients were lost to follow up, and all were included in the review.

1. Preoperative evaluation [Table 2; Table3]

The eight hips evaluated included five female and two male patients, one male with bilateral involvement, with the side involved equal at four each for the right and left hip.

The average age at presentation was 12y 11/12 (10y 9/12 – 14y 5/12).

Duration of symptoms prior to presentation was 57.75 days on average (7 – 180 days), with the time from admission to surgery on average 16.5 days (5 – 46 days).

Bilateral modified Dunn procedures were performed on one of the patients in the study group. The delay between the first and second procedure account for the 46 days from admission to the date of surgery.

Preoperative evaluation included grading of the slip, and included the severity; expressed as mild, moderate, and severe (1/3, 2/3 and 3/3 slippage of the epiphysis when compared to the width of the femoral neck respectively), and the lateral Southwick angle; expressed as mild, moderate and severe (slippage of < 30 deg, 30 – 60 deg, and > 60 degrees respectively).

The preoperative stability of the SUFE was determined by the ability / inability to bear weight as described by Loder [13], relating to a stable / unstable slip.

Preoperative range of motion was inconsistently reported due to pain, and the fact that five of the hips were classified as unstable and manipulation was thus contraindicated, made preoperative documentation of the range of motion obsolete.

Table 2: Patient demographics and pre-operative grading of slipped capital femoral epiphysis (SUFE)

PATIENT	GENDER	AGE AT PRESENTATION	SIDE	DURATION OF SYMPTOMS	LATERAL SLIP ANGLE	SLIP GRADE	STABILITY
1	Male	13y 3/12	Right	6 months	35 degrees	Moderate	Stable
2	Female	10y 9/12	Right	3 months	40 degrees	Moderate	Unstable
3	Female	13y 8/12	Left	15 days	45 degrees	Moderate	Stable
4	Female	14y 3/12	Left	3 months	40 degrees	Moderate	Stable
5	Male	11y 11/12	Right	1 week	46 degrees	Moderate	Unstable
6	Male	11y 11/12	Left	1 week	36 degrees	Moderate	Unstable
7	Female	14y 5/12	Left	2 months	41 degrees	Moderate	Unstable
8	Female	13y 8/12	Right	1 week	30 degrees	Moderate	Unstable

Table 3: Demographic and pre-operative averages

AGE AT PRESENTATION	GENDER	DURATION OF SYMPTOMS	SIDE INVOLVED
12y 11/12 (10y 9/12-14y 5/12)	Male 3 Female 5	57.75 days (7-180 days)	Right 4 Left 4
SLIP ANGLE	SLIP GRADE	STABILITY	TIME TO SURGERY
39.13 degrees (30-46 deg)	moderate	Unstable 5 Stable 3	16.5 days (4 – 46)

Preoperative special investigations included MRI and Tc bone scanning for early detection of avascular necrosis.

MRI was performed on a total of three hips and preoperative bone scanning on two hips with SUFE. Inconsistency with regards to preoperative scanning was the result of non-availability of the facility at the time of presentation, with a lengthy waiting period prior to scanning leading to these tests not being done on all patients.

Blood workup for endocrinopathies was done on patients with bilateral involvement, and those with young age at presentation.

2. Intraoperative evaluation

Patients were prepared for theatre with appropriate pre-operative workup, including a crossmatch and two units of blood (RBC) on standby.

Patients were operated on in the lateral position, and a transtrochanteric surgical dislocation procedure was performed, as described by Ganz [40].

Fig 9: The patient is placed in a full lateral position on a radiolucent table.



Fig 10: The trochanteric osteotomy thickness should not exceed 1,5 cm.

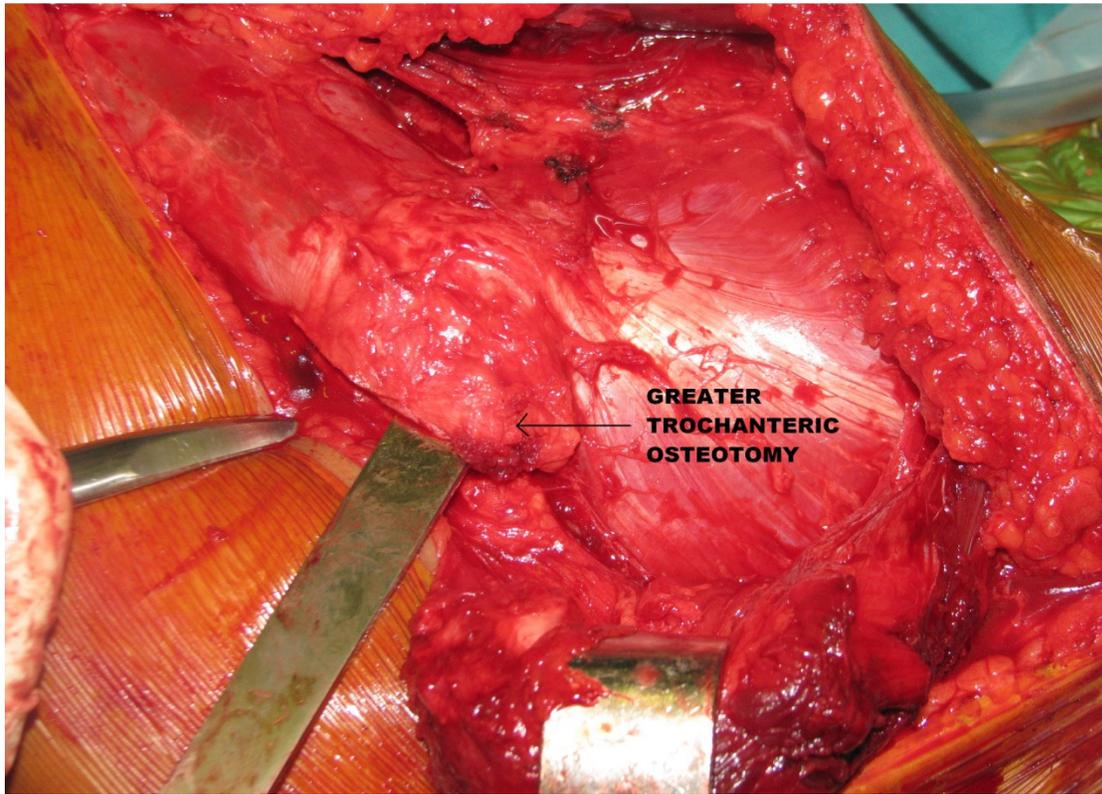
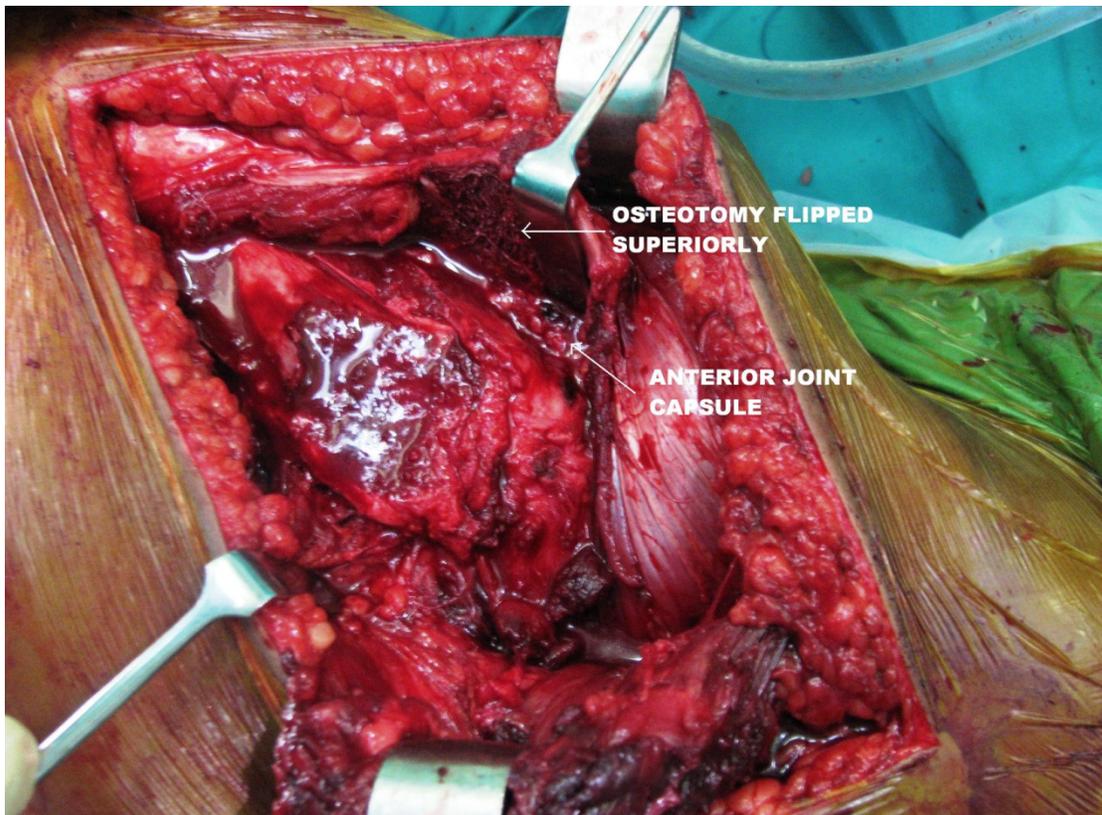
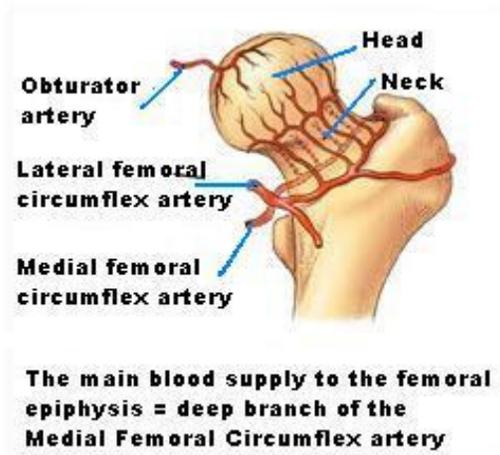


Fig 11: The trochanteric osteotomy is flipped antero-superior to expose the anterior hip capsule.



The main blood supply to the femoral head is from the deep branch of the medial femoral circumflex artery (MFCA) [14].

Fig 12: Blood supply to the femoral head.



The trochanteric osteotomy is flipped antero-superior, and allows exposure of the anterior capsule of the hip joint, while protecting the integrity of the external rotators [40].

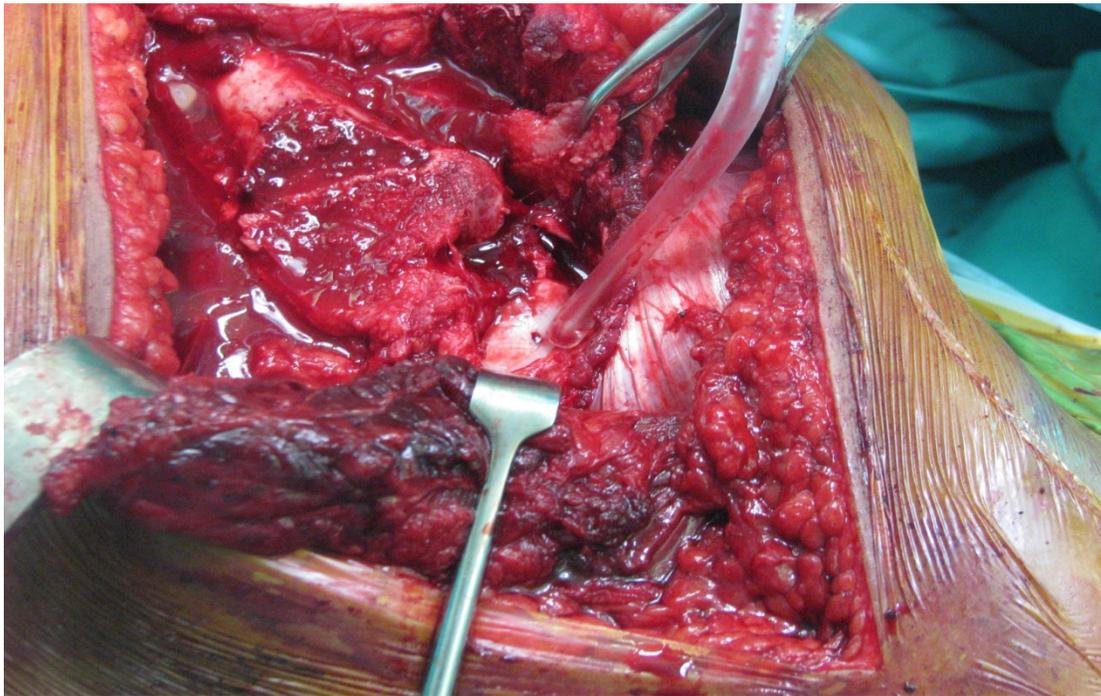
The capsular incision is done in a Z fashion to protect the piriformis fossa soft tissue, and to allow anterior dislocation of the femoral head [40].

During dislocation of the hip the MFCA is protected by the intact obturator internus muscle.

This exposure allows an almost 360 degree view of the femoral head, and a full 360 degree view of the acetabulum, by allowing a gap of up to 11 cm between the head and the acetabulum [40].

After dislocation of the femoral head, the vascularity of the epiphysis can be determined by drilling of a 2mm hole into the head and observing bleeding [39].

Fig 13: Anterior exposure of the femoral head, and intra operative determination of vascularity of the epiphysis through drilling of a 2 mm hole into the head.



We determined the intra-operative vascularity of the femoral head by inserting a mini epidural spinal needle (19G) into the femoral head prior to dislocation, and repeated the process after reduction of the femoral head [fig 14].

The epidural spinal needle was connected to an arterial line and transducer, and a pulse trace on the anaesthetic monitor confirmed an intact vascular supply to the epiphysis [fig 15].

This technique was performed on seven of the eight hips involved, and related to an accurate assessment of intra operative blood supply to the femoral head, as well as an accurate predictor of the potential development of avascular necrosis of the femoral head. In one patient the presence / absence of blood flow to the epiphysis was not documented.

Laser Doppler flowmetry [44] probes can also be used to determine epiphyseal perfusion, but is not readily available at our institution.

Fig 14: Intra operative vascularity determined by inserting a paediatric spinal needle coupled to an arterial line and transducer into the femoral head.

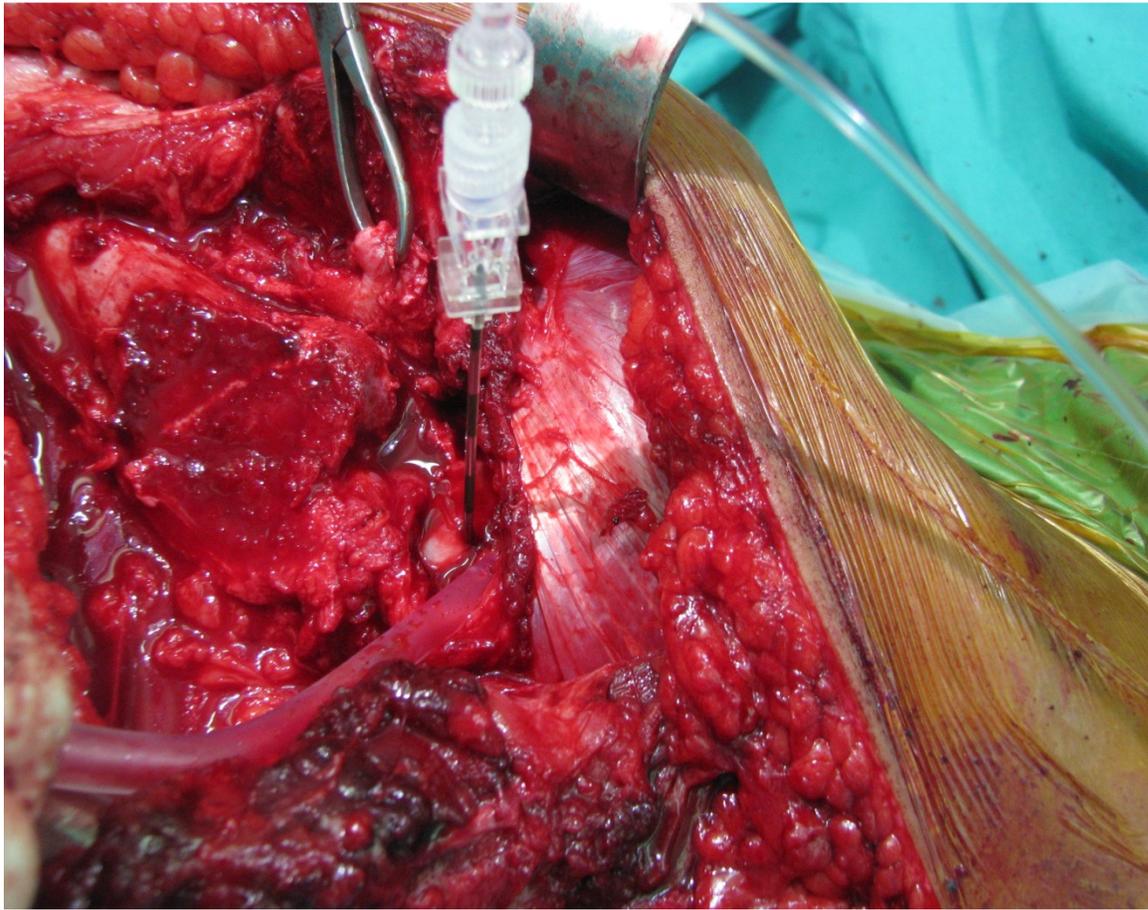
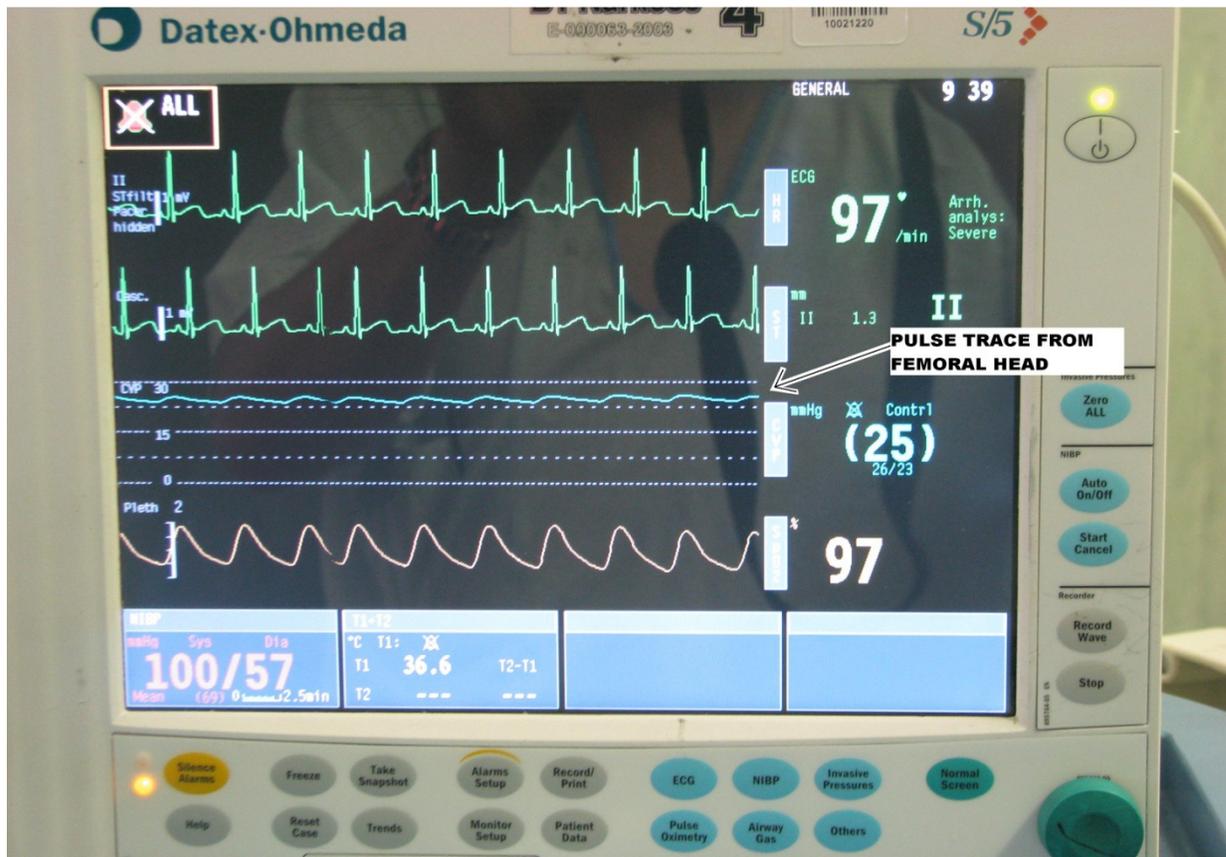


Fig 15: A pulse trace on the anaesthetic monitor confirms an intact vascular supply to the femoral head.



By developing an extended retinacular flap through subperiosteal release around the femoral neck and head, and by protecting the integrity of the external rotators, a soft tissue flap is created that holds the vessels that supply the epiphysis [40].

After manual separation of the epiphysis from the metaphysis, the residual callus from the posterior aspect of the femoral neck is removed, and the remaining growth plate removed by curettage [39].

Care is taken not to damage or put unnecessary tension on the retinacular flap, thereby damaging the blood supply to the head [40].

After contouring the femoral neck, the epiphysis is reduced onto the neck, again avoiding tension to the retinaculum [39].

We use the tibial tunnel guide from an anterior cruciate reconstruction set to determine our 2x cannulated pin placement when fixing the epiphysis to the femoral neck [fig 16].

Fig 16: Using the tibial tunnel guide from the anterior cruciate reconstruction set, we can accurately determine pin placement.

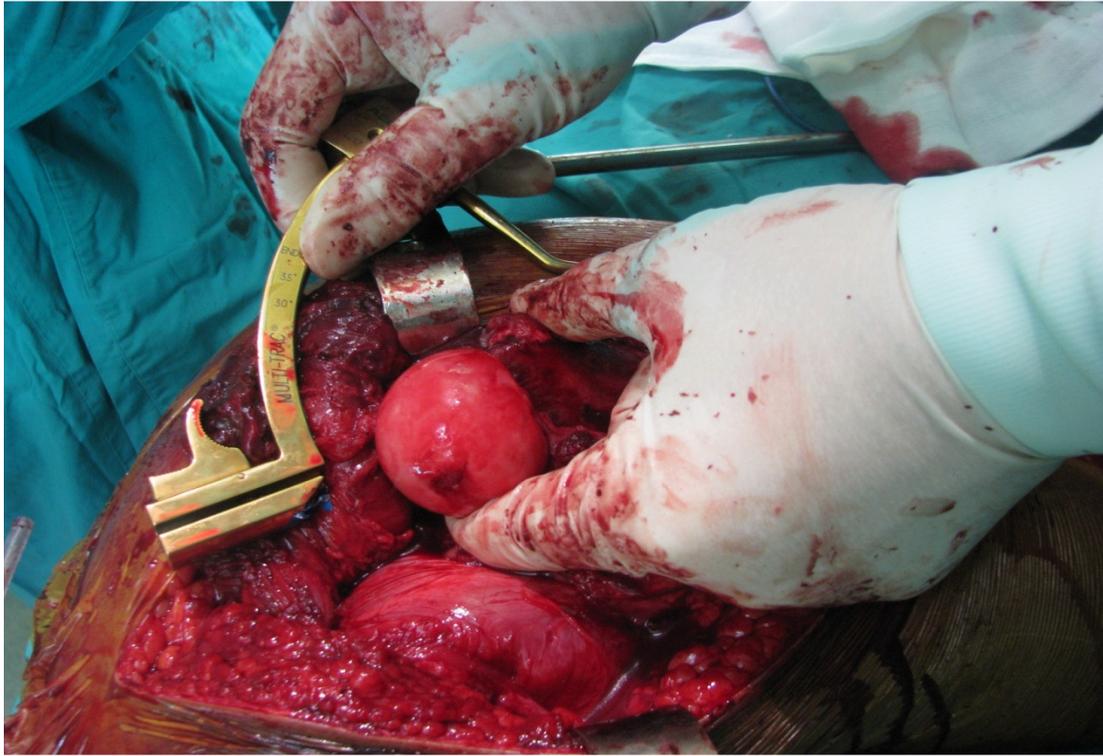
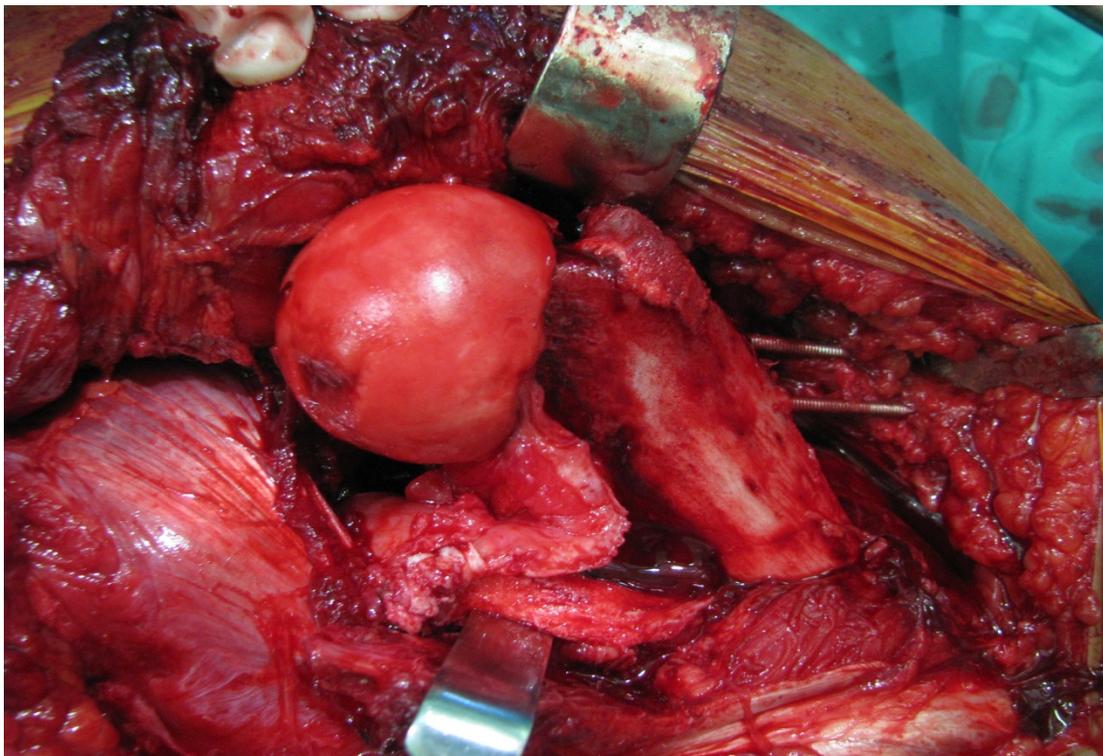


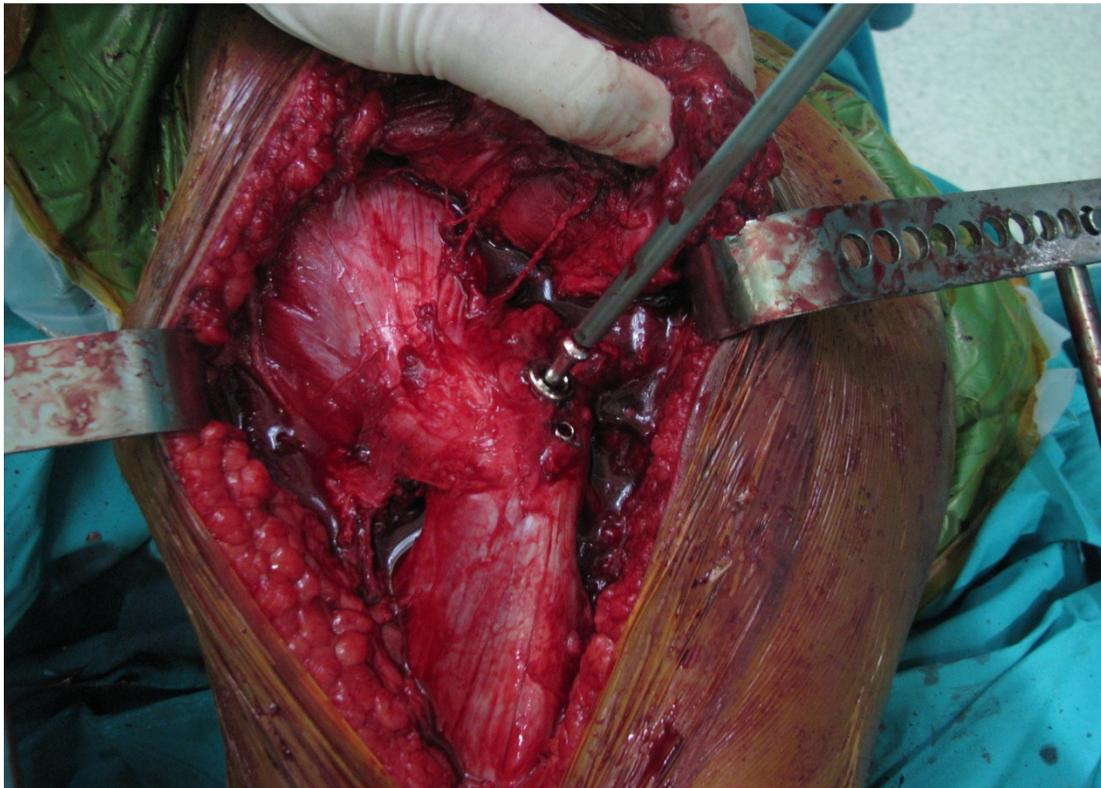
Fig 17: After reduction and fixation of the femoral head to the neck, the proximal wires are cut flush with the head and buried subcondral.



After reduction of the femoral head, the blood supply is checked again through insertion of the spinal needle and observing a pulsatile trace, and the tension on the retinaculum is evaluated clinically [39].

Fixation of the trochanteric osteotomy is done with two 6.5 mm cannulated screws [fig 18].

Fig 18: Fixation of the trochanteric osteotomy with two 6.5 mm cannulated screws.



3. Post operative evaluation

a) Early post operative period

The patient is stabilized and transfused as indicated by post operative Hb < 8 g/dl.

Post operative x-rays include an AP pelvis and lateral view of the involved hip. Frog leg lateral views are too painful in the early period, and we rely on shoot through lateral views to determine the reduction obtained.

Hospital stay includes a three week in-hospital physiotherapy program. Due to the socio-economic conditions of most of our patient population, out of hospital physiotherapy and full time patient care is not readily available, and therefore this protocol applies to all our patients. We do not have a bed occupation constraint imposed on us, and thus we can optimize our patients' rehabilitation in the early post operative period.

During the first week strict bed rest is imposed, with an in bed physiotherapy program focussing on hip range of motion exercises, especially flexion and internal rotation.

We do not have Continuous Passive Motion (CPM) machines available to our patients on a regular basis, and need to rely solely on our physiotherapists for range of motion exercises.

During the second week toe touch mobilization with crutches is encouraged. Range of motion exercises continue during the full three week period.

Sutures are removed at 10 to 14 days post operative.

Toe touch mobilization with crutches continues until early signs of union, usually at six weeks post operatively.

A check x-ray is done prior to discharge to confirm reduction, and repeated with the follow examination at six weeks post operatively.

Signs of epiphyseal and trochanteric union are evaluated at first follow up (six weeks). If adequate signs of union, as judged radiologically by callus formation, are evident, the patient can progress to partial weight bearing with crutches for another six weeks.

At the 3/12 post operative visit, if epiphyseal and trochanteric union is confirmed and no pain is experienced with partial weight bearing, the patients are mobilized full weight bearing.

Normal activities are permitted at three months post surgery, and participation in sporting activities nine months after surgery.

X-rays taken post operatively were used to evaluate the reduction achieved with the modified Dunn procedure.

Reduction was measured by comparing pre- and post reduction lateral views of the affected hip, and measuring the lateral Southwick angle [21].

The post operative reduction average can then be compared to the normal Southwick angle (10 degrees posterior on a lateral view), to determine the amount of anatomical reduction achieved with this procedure. The amount of slip angle correction can also be calculated by this method of comparison.

b) Late post operative period

For the purpose of this study patients were followed up at an average of 18.44 months (1.54y) post operatively, and examined clinically to determine the range of motion.

Flexion of the affected hip, and internal / external rotation in flexion were documented, tabulated, and averages determined.

International functional scoring systems were used to determine outcome, and included both the Harris Hip Score [45] and the WOMAC system [46]. These include patient self evaluation of function of daily living, and documentation of the range of hip motion found during examination.

Radiological evaluation included the documentation of any complications that may arise as a result of the procedure, and include possible avascular necrosis, chondrolysis, heterotrophic ossification, trochanteric non union, loss of reduction, and hardware breakage.

Clinical documentation of complications included leg length discrepancy, abductor weakness, infection, nerve palsies and femoroacetabular impingement.

The pre-operative classification, post operative evaluation of range of motion, documentation of the outcome scores, and radiological evaluation of the reduction achieved, were all done by the principal investigator, and the results verified by the supervisor of this study.

All results were tabulated and averages determined. All complications were noted. Where results are not included in the final outcome, a clear explanation of such a decision is given during the result discussion.

Table 4: Post operative radiological and clinical evaluation

PATIENT	FOLLOW UP (months)	LATERAL SOUTHWICK ANGLE	SLIP ANGLE CORRECTION	FLEX	FLEX/IR	FLEX/ER	HARRIS HIP SCORE	WOMAC SCORE
1	6	155 degrees	20 degrees	110	30	30	96.01	98.40
2	40	166 degrees	36 degrees	110	40	40	98.01	93.80
3	24	185 degrees	60 degrees	90	10	30	97.87	95.30
4	5	170 degrees	40 degrees	100	30	40	96.00	98.40
5	27	179 degrees	60 degrees	60	5	10	51.15	73.40
6	26	161 degrees	27 degrees	95	25	20	99.87	99.20
7	17	165 degrees	36 degrees	30	30	5	80.84	82.00
8	26	170 degrees	30 degrees	95	10	30	90.00	95.30

Table 5: Post operative radiological and clinical averages

FOLLOW UP	LATERAL SOUTHWICK ANGLE	SLIP ANGLE CORRECTION	FLEXION
18.44 months (1.54 y)	168.88 deg (155 -185)	37.88 deg (20 – 60)	90 deg
			* 100 deg
FLEXION / INTERNAL ROTATION	FLEXION / EXTERNAL ROTATION	HARRIS HIP SCORE	WOMAC SCORE
25 deg	27.85 deg	94.08 (80.84 – 99.87)	94.63 (82.0 – 99.20)
* 25 deg	* 31.6 deg		

* The average range of motion and functional outcome scores achieved on patients who did not develop major complications.

Explanation of results: Functional averages were calculated on seven of the eight hips involved.

One patient had pre- and intraoperative confirmation of AVN and was thus not included in the calculation for range of motion or functional outcome, but included in the radiological evaluation of the reduction achieved.

* Results achieved when averages for range of motion were calculated in patients without major complications (chondrolysis developed in one patient resulting in a decreased range of motion, influencing the average result in such a small study group significantly).

RESULTS

A. Radiological reduction

All SUFE were graded pre-operatively as moderate, with an average slip angle measured on a lateral view of the hip, of 39.13 degrees (30 - 46 degrees).

Of these, five were graded as unstable, and three stable, according to the classification of Loder [13].

The average post operative slip angle, taken on a comparative lateral view of the hip, showed an average post operative slip angle of 168.88 degrees (155 - 185 degrees).

This relates to a range of 15 degrees under correction to 15 degrees over correction, when compared to the normal lateral Southwick angle [21] of 170 degrees. This diverse range was especially evident during our earlier attempts, and highlights the technical difficulty of this procedure. During our later attempts we achieved a perfect reduction in two of our patients, with post operative lateral Southwick angles of 170 degrees (10 degrees posterior).

The procedure led to an average slip angle correction of 37.88 degrees (20 - 60 degrees) in our patient series.

Fig 19: Later attempts led to near perfect reduction of the lateral Southwick angle in two patients, demonstrated here with a frog leg lateral view taken on patient no.8



B. Range of motion and functional outcome.

Patients were followed up at an average of 18.44 months (1.54 years), ranging from 5/12 to 3y 4/12 post surgery.

Passive range of motion was documented with an average for flexion, flexion internal rotation, and flexion external rotation of 100 degrees, 25 degrees, and 31.6 degrees respectively, in patients who did not develop major complications [Table 5].

One patient with pre- and intraoperative confirmation of AVN was left out of the final calculation with regards to range of motion and functional scores, because the poor clinical result can not be directly contributed to the procedure.

One patient developed chondrolysis, which had a severely negative impact on the interpretation of the **average** post operative range of motion in such a small sample group. To truly measure the range of motion achievable through this procedure, the average values were calculated on patients who did not develop major complications [Table 5*]. This patient was however included in determination of the functional outcome scores.

One of the patients who developed focal AVN was included in the functional outcome analysis due to inconclusive preoperative confirmation of AVN, as well as failure to document the intraoperative vascular status of the femoral epiphysis. Thus there was not enough evidence to assume with certainty that the AVN was not caused by the procedure.

Functional outcome was measured through both patient self evaluation and the objective functional evaluation by the surgeon, and standardized through the use of two international scoring systems, namely the Harris Hip Score [45] and the WOMAC [46] score.

The Harris Hip Score contains both a self evaluation section completed by the patient, and a clinical evaluation of range of motion measured by the surgeon, and averaged 94.08 in our study group.

The WOMAC is a questionnaire in which the patient evaluates his/her own function of daily living activities, and averaged 94.63

Both these outcome based scores related to an excellent post operative functional result, and included patients who developed major complications [Table 5].

C. Complications

None of the patients in this study developed avascular necrosis as a direct result of the procedure.

One patient had pre- and intraoperative confirmation of AVN.

One patient, who developed focal AVN, had an inconclusive result, due to failure to document the intraoperative vascular supply to the femoral head, coupled with questionable preoperative findings on special investigations.

The abnormal special investigations in the patient with focal AVN included a MRI scan, which reported abnormal changes in the femoral neck possibly associated with weight bearing, and a bone scan which queried changes associated with avascular necrosis.

The resultant development of focal AVN in this patient can thus not, with certainty, be contributed to the procedure.

One patient developed post operative chondrolysis, not due to pin penetration, with resultant painless, decreased range of motion.

One patient had a positive Trendellenburg gait due to abductor weakness.

There was no incidence of head-neck or trochanteric delayed or non union.

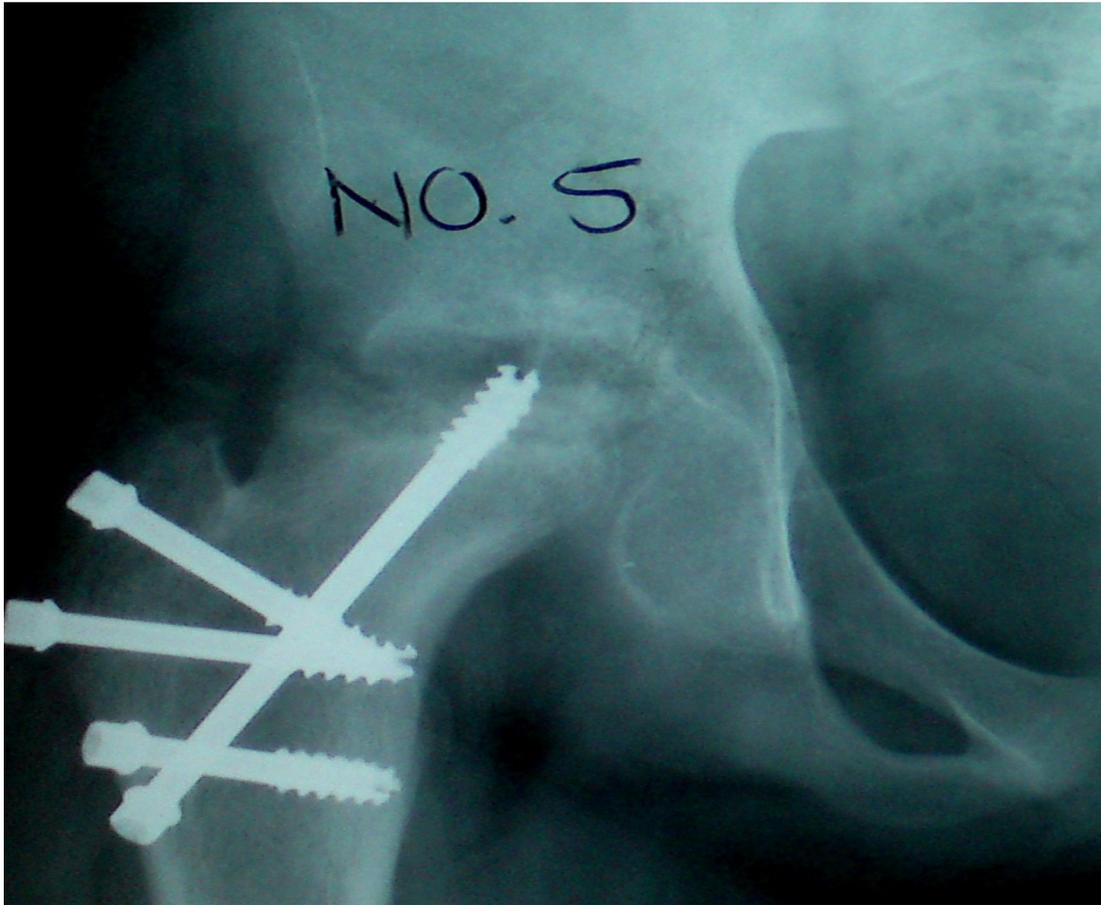
No patients developed heterotopic ossification or femoroacetabular impingement post operatively.

None of the patients had loss of reduction, hardware failure, infection, or nerve palsies.

Leg length discrepancy averaged 1.1cm (1- 1.5cm), and was found to be of no clinical significance.

Hardware was removed in one patient only, due to collapse of the femoral head secondary to AVN, with metal protruding into the hip joint.

Fig 20: Collapse of the femoral head with hardware protrusion into the hip joint necessitated metal removal in this patient.



DISCUSSION

Slipped upper femoral epiphysis (SUFE) remains a debilitating disease in our young population group. The development of osteoarthritis at an early age is probably one of our biggest concerns, second only to the development of avascular necrosis of the femoral head with subsequent collapse. The accelerated onset of osteoarthritis is thought to result from femoroacetabular impingement, caused by altered hip biomechanics, due to epiphyseal displacement in a postero-inferior direction, with abutment of the femoral neck against the acetabulum during range of motion [3].

With this in mind, it stands to reason that, if we can restore the normal anatomy and biomechanics of the hip, while safely limiting the risk of causing AVN through open reduction, we might have found a way to better manage this problematic condition.

We believe that by performing a subcapital realignment procedure at the CORA (Centre Of Rotational Angulation), near anatomic reduction can be obtained.

The modified Dunn procedure [39] combines this technique with a surgical dislocation (Ganz) [40], to limit the risk of AVN.

We have performed this procedure on all the patients included in this study, at Tygerberg Hospital, Cape Town.

The primary aim of this study was to determine if we can achieve near anatomical reduction of the proximal femur and improve the functional outcome of our patients, with little to no risk of avascular necrosis or the development of other major complications as a direct result of the procedure.

Secondly, we wanted to see if the results achieved internationally, could be reproduced in the state health sector in South Africa.

A shortfall of this study is the small number of patients included in the sample group, with **any** complication therefore being of statistical significance when determining averages.

We do see this as a pilot study, and with more data and patients added in the future, the statistical value will no doubt increase.

We had one major complication, namely chondrolysis, which developed in a patient after the procedure. Possible causes are genetic predisposition (black female) and immobilization prior to surgery (16 days) [42]. There was no pin penetration into the joint, either transient or permanent.

We had no confirmed incidence of avascular necrosis caused by the procedure in any of our patients. One patient developed focal AVN after the procedure. In this patient the preoperative bone scan suggested possible AVN. Intraoperative vascularity was

however not documented, and therefore the development of AVN cannot with certainty be contributed to the procedure.

We found that preoperative bone scanning accurately predicted possible AVN in all patients, with MRI scanning found to be less predictive during the preoperative period.

Positive intraoperative monitoring of blood flow to the epiphysis correlate well with femoral head survival post operatively.

We therefore feel that intraoperative monitoring of epiphyseal blood flow is essential, and that a bone scan, as a preoperative special investigation, is a more accurate predictor of the potential to develop AVN.

Near anatomical reduction was achieved as evident from our post reduction lateral Southwick angle average of 168.88 degrees, compared to the normal of 170 degrees [21]. The procedure has a steep learning curve, and remains technically demanding, as evident from our improved radiological reductions obtained during our later cases.

We had excellent functional outcome scores in all patients that met the inclusion criteria, with the Harris Hip Scores [45] and WOMAC [46] scores both above 94 points.

Range of motion was improved through restoration of normal hip biomechanics, especially flexion-internal-rotation (average range 25 degrees), when compared to an average flexion-internal-rotation range of motion of 11 degrees found in one study after in situ pinning of SUFE [38], and comparable results with regards to flexion and flexion-external-rotation.

This study has proven that a modified Dunn procedure can restore near normal hip anatomy and biomechanics, with little to no increased risk of AVN, in moderate to severe slipped upper femoral epiphysis, without major complications.

Femoroacetabular impingement is limited, and thus the theoretical risk for developing early onset osteoarthritis, caused by impingement, is diminished.

The results achieved in this study, although in a small sample group, are comparable to those published internationally [39] with regards to the degree of radiological reduction obtained, and post operative range of motion and functional outcome, with an equal low incidence of major complications as a direct result of the procedure.

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