CHILDREN

Avascular necrosis as a complication in the management of developmental dysplasia of the hip

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INTRODUCTION

Avascular necrosis (AVN) of the proximal femoral epiphysis is an iatrogenic complication of treatment for developmental dysplasia of the hip (DDH), and does not occur during the natural history of the untreated hip. The objective is to produce a congruous concentric joint and minimize premature degenerative disease and disability during young adult life, by achieving early reduction of the hip with acetabular augmentation or femoral realignment when necessary. AVN causes a spectrum of damage to the epiphysis and physis and the classification by Kalamchi and MacEwen is in wide usage.1 The significant late sequelae of AVN are abnormal contour of the femoral head and neck which contribute to subluxation of the hip, a short femoral neck causing abductor insufficiency and leg length inequality. It may be a devastating complication which can result in a poorer outcome than the original pathology of DDH, and is particularly disastrous if the previously normal contralateral hip is affected.

AETIOLOGY

Splintage

There are many conservative methods for treating reducible subluxation and dislocation detected in the first few weeks of life, all of which position the hip in flexion and abduction. In the UK the Pavlik harness is a popular dynamic splint. Splintage in extreme abduction (Lorenz position) should be condemned as it increases the risk of AVN.2 In light of the fact that Gardiner and Dunn showed a resolution of 71% of clinically dislocatable hips at birth by the age of 2 weeks, a strategy of initial observation and serial ultrasound scans can be followed, but is reliant on the availability of this technical expertise and on parental compliance.3 If it is decided to treat clinically detectable instability in the newborn with immediate splintage, it is essential that audit of the splintage undertaken confirms an extremely low rate of AVN. The policy at Oswestry has been to treat clinically reducible hips in a Von Rosen splint (abduction = 60°) during the first 3 weeks of life and to use the Pavlik harness thereafter until 12 weeks of age. This policy implemented for the past 20 years has been associated with an AVN rate of 0.93%, which is comparable to the best results in the literature including Von Rosen’s original series with an AVN rate of < 1%.4 For clinically irreducible hips presenting up to 6 months of age, the Pavlik harness may be tried for a short period of 3 weeks, but if there is no improvement it should be discontinued. Meticulous supervision of the harness and maintenance of the optimal degree of hip flexion in the rapidly growing infant is essential. If the harness becomes too small, the hip is vulnerable to inferior subluxation. The harness is set with 100° of flexion to achieve reduction and 90° to maintain it. The incidence of AVN in this group in our series was 4.5%.

Pre-reduction traction

This may be used to reduce the incidence of AVN, but there is scant literature to prove that it is beneficial. Certainly, traction in extreme position causes AVN5 and overture traction without extreme position avoids this problem.5 Kutlu showed that preoperative traction was not protective for AVN in his series.7

Closed reduction and spica treatment

Examination under anaesthesia and arthrography facilitate gentle manual reduction of a persistently subluxed or dislocated hip, when abduction splintage fails and
where there are no obstructive factors. For infants presenting over the age of 6 months, this treatment is undertaken without attempting prior splintage. Percutaneous adductor longus tenotomy can be added if hip abduction is restricted despite satisfactory medialization of the head into the acetabulum. This is to reduce muscle tension which increases the pressure across the joint, which in turn contributes to AVN. Experimental animal work has demonstrated that the cartilaginous femoral epiphysis has a system of terminal end-arterioles. It has been postulated that pressure on the end-arterioles after reduction impairs the vascular supply to the femoral head more when it is compressible and wholly cartilaginous, than when the head is ossified and has anastamosing vessels. The reduction should be maintained with a hip spica plaster which should be applied in the ‘human position’ of approximately 60° of abduction, 90° of flexion, and with moulding behind the trochanteric region to prevent redislocation. Internal rotation of the legs is avoided as this may impair the epiphyseal circulation, possibly either by ‘wringing’ the posterior capsular retinacular vessels or by ‘pinching’ the ascending branch of the medial circumflex femoral artery. A poor initial reduction of the hip has been documented to carry up to a 57% risk of AVN.9

Open reduction
An open reduction is necessary when medialization and closed reduction is prevented by the psoas tendon, inferior capsular contracture, inverted limbus and hypertrophy of the ligamentum teres. The medial approach may be undertaken through the adductor brevis/magnus interval (Ludloff approach).10 The hip must not be reduced under excessive tension and care must be taken not to damage the branches of the medial circumflex vessels as this may contribute to AVN. A capsulorrhaphy is not performed during the medial open approach and therefore the post-operative maintenance of reduction is achieved by a plaster spica in the ‘human position’ as for a closed reduction. This approach is usually used for up to 18 months of age for isolated infero-medial obstructive factors, and Weinstein reports the rates of AVN for the medial approach being 5%–10%.11

Anterior open reduction through a modified Smith-Peterson approach is preferred when the capsule and labrum, the so-called inverted limbus, is a significant obstructive factor. Capsulorrhaphy reduces the duration of splintage necessary. The position in a spica is with the hip in approximately 20° of flexion, abduction and internal rotation.

In circumstances where the hip reduction is under tension, a shortening femoral osteotomy should be performed to minimize the risk of pressure injury to the femoral head. This will incorporate correction of excessive anteversion. The technique for judging on-table the amount of shortening necessary is to first insert the fixation device (e.g. mini-Richards hip-screw) along the femoral neck and perform a sub-trochanteric osteotomy. The femoral head is then reduced into the exposed acetabulum and the overlap of the femur at the osteotomy site represents the length of the segment of femur to be excised prior to fixation. MacEwen reports that in his series open reduction performed alone had the highest AVN rate.12 Our own experience suggests that the addition of a Salter osteotomy at the time of anterior open reduction does not further increase the incidence of AVN from 8%,13 but that femoral shortening at the time of reduction, rather than delayed for some weeks, has the most beneficial effect in reducing the incidence of AVN.

CLASSIFICATION
AVN can be defined using the following criteria: failure of appearance of the ossific nucleus, failure of growth in the existing nucleus during 1 year or longer after reduction, broadening of the femoral neck and increasing density followed by fragmentation of the ossific nucleus. The best known classification for avascular necrosis of the proximal femur and capital femoral epiphysis is that originally described by Kalamchi and MacEwen (Fig. 1).1 There are four patterns of growth disturbance described. The classification relates the severity of the associated physeal damage and subsequent deformity which evolves during growth.

MANAGEMENT
Grade I
The radiological features characterizing this grade of AVN are a delay in appearance of the ossific nucleus or flattening and fragmentation of the ossific nucleus. The head within a head appearance may be seen. Subsequent growth usually recovers the spherical femoral head shape (Fig. 2). There may be minor loss of head height or coxa magna at maturity with occasional minor medial deficiency of the head. Changes in the neck at maturity are not seen in this group. This type of AVN does not normally require later treatment.

Temporary patchy or irregular ossification in a previously unossified epiphysis which then progressively enlarges may represent progress rather than ischaemic change (Fig. 3). Coxa magna is a hypertrophy and its aetiology may be multifactorial. It may represent enlargement of the wholly cartilaginous femoral epiphysis, which due to dislocation, is unrestrained by the normal containment modelling influences of the acetabulum.
Hyperaemia during post-operative healing may contribute to overgrowth in the absence of previous AVN.14 If all hips with coxa magna are included as Grade I AVN it exaggerates the incidence.

Grade II

The cardinal criterion for diagnosis of this grade is involvement of the lateral physis. Early signs which differentiate it from Grade I include lateral physis irregularity, notching and a lateral metaphyseal defect (Fig. 4A). The damage to the physis produces abnormal growth with a more pronounced valgus tilt if the lateral tether is small and a shorter femoral neck if the tether is large. The valgus neck produces progressive acetabular uncovering of the femoral head during adolescence, and a femoral varus osteotomy with or without an acetabular containment procedure may be required (Figs. 4A–C). The treatment for the relative trochanteric overgrowth and functional leg length inequality which occurs occasionally is discussed under Grade III.

Grade III

Central physisal arrest categorizes Grade III AVN. Early radiographic hints are central irregularity or bridging on the frog lateral view and with growth the femoral neck remains short without significant alteration in the neck-shaft angle (Figs. 5A). Trochanteric physisal growth proceeds unhampered producing trochanteric overgrowth relative to the neck, which weakens the abductor muscles and eventually causes limping.

Relative overgrowth of the trochanter can be measured using the articular–trochanteric distance (ATD) which is the vertical height in the long axis of the femur from the top of the head to the tip of the trochanter. Reversal of this relationship by 5 mm or more has been associated with a Trendelenburg lurch.15 Optimally, a trochanteric epiphysiolysis is performed at 8 years of age through a direct lateral approach to the greater trochanter, and a fine-angled Chow curette is used to remove the lateral half of the physis (Fig. 5B and C). The cancellous bone exposed proximal and distal to the removed phyleal plate is interleaved into the gap. Overzealous excavation of the physal plate could result in abductor detachment and caution is advised. Appositional growth continues at the abductor insertion but increasing trochanteric height is halved. This abnormality can be addressed after maturity by trochanteric advancement distally (Fig. 8B).

Leg lengths require monitoring throughout growth as a discrepancy is expected in Grade III AVN. Careful clinical estimation of leg length discrepancy (LLD) is important using measured wood blocks placed beneath the patient’s short leg until the spine is straight and on forward flexion at the hips, the posterior pelvis appears horizontal. This is particularly important if there is coexistent pathology such as a short heel, because radiological techniques measure from femoral head to tibial plafond. Grid films were used traditionally and are more accurate than CT scansograms, which, though they require less radiation, may be subject to a magnification error due to manual pixel placement on a small-scale image (Fig. 6A).

LLD can be addressed by lengthening the shorter leg but is not advisable in circumstances where the hip above was dysplastic initially and then developed AVN. Lengthening could further predispose to pain or secondary subluxation. Shortening the longer leg can be achieved during growth by an appropriately timed epiphysiolysis. Several methods of prediction of LLD at maturity are described in the literature and can assist in estimating the timing and site(s) for epiphysiolysis. Moseley16 based his straight-line graph on Anderson’s ‘growth to come’ charts and the length of the longer leg is plotted above the shorter leg. Skeletal age may differ from chronological age and the Greulich and Pyle atlas estimates skeletal age using left-hand radiographs. Ideally, at least three
Figure 2  (A) Grade I AVN left hip with early mottling of ossific nucleus. (B) Grade I AVN with failure of growth of ossific nucleus. (C) Grade 1 AVN with coxa magna.

Figure 3  (A) Right hip capital femoral epiphysis begins delayed ossification. (B) Ossific centre enlarging. (C) Coxa magna without evidence of preceding avascular change.
measurements of leg lengths and bone age during growth are recorded and plotted and the bone age is extrapolated to calculate an estimation of LLD at maturity. The recorded leg length plots are joined to make a straight line for each leg. Depending on the distance between these lines there are three available angled line therapeutic options; tibial epiphysiodesis (shallowest line), femoral epiphysiodesis, and both tibial and femoral epiphysiodesis (steepest line to correct larger LLD). The timing of the procedure chosen is then expressed either as bone age or length of the longer leg. Using Moseley’s method in our unit an audit of 50 patients showed an 87% success rate in achieving LLD correction to be within 1 cm of equality at skeletal maturity. Menelaus popularized White’s linear equation of 9 and 6 mm/year for distal femoral and proximal tibial growth, respectively, with skeletal maturity at age 14 years in girls and 16 years in boys. Eastwood and Cole described a simple graphic method based on chronological age. Epiphysiodesis is performed by drilling and curettage of the distal femoral and proximal tibio-fibular physeal plates through a 2 cm lateral skin incision sited over the appropriate physis (Fig. 6B and C).

Grade IV
The severely damaged femoral head does not address the acetabulum normally to allow the pelvic dysplasia to remodel with growth. Articular deformity and subluxa-
Figure 5  (A) Grade III AVN L hip early central physeal irregularity. (B) Grade III AVN with coxa brevis. (C) Grade III AVN post-trochanteric epiphysiodesis.

Figure 6  (A) CT scannograms showing shortening of left leg with Grade IV AVN of the patient's left hip. (B) Drilling over guidewire during epiphysiodesis of contralateral longer leg. (C) Curettage of drill tracts during epiphysiodesis of distal femur to address leg length discrepancy.
tion usually persist (Fig. 7B). Early radiographic features of this group include widening, shortening, medial beaking and true varus of the femoral neck. This results in a stiff deformed joint which usually predisposes to pain and arthritis in the adolescent and young adult.

Acetabular redirection with a Salter pelvic osteotomy may be undertaken during the avascular phase to influence the mechanics and further growth of the joint (Fig. 7B). In an older child, a painful irreducible subluxation may be helped by acetabular augmentation using the Chiari (Fig. 8A and b) or Staheli shelf (Fig. 9) techniques. A distal trochanteric advancement may be combined with acetabular augmentation (Fig. 8B). Functional leg length inequality can be addressed surgically as described above for Grade III AVN (Table 1).
REFERENCES


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<tr>
<th>AVN grade</th>
<th>Complication</th>
<th>Treatment</th>
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<tbody>
<tr>
<td>I</td>
<td>Coxa magna but congruous joint</td>
<td>Nil</td>
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<tr>
<td></td>
<td>Coxa valga</td>
<td>Varus femoral osteotomy</td>
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<tr>
<td>II</td>
<td>Secondary subluxation with growth</td>
<td>Trochanter epiphysiodesis (age 8 years)</td>
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<td>III</td>
<td>Relative trochanteric overgrowth (coxa brevis) +</td>
<td>Contralateral femoral + tibial epiphysiodesis (approx 3 years before maturity)</td>
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<td></td>
<td>Leg length inequality (4–5 cm)</td>
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<td>IV</td>
<td>As for Grade III +</td>
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<td>Non-congruous joint subluxation or</td>
<td>Early pelvic osteotomy e.g. Salter (to contain and model the head with growth) or</td>
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<td></td>
<td>Persisting acetabular dysplasia +</td>
<td>Late augmentation as salvage (Chiari or shelf) +</td>
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<td></td>
<td>Abductor dysfunction</td>
<td>Distal trochanteric advancement</td>
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