A protocol for the use of closed reduction in children with developmental dysplasia of the hip incorporating open psoas and adductor releases and a short-leg cast

MID-TERM OUTCOMES IN 113 HIPS

**Aims**

Our aim was to assess the effectiveness of a protocol involving a standardised closed reduction for the treatment of children with developmental dysplasia of the hip (DDH) in maintaining reduction and to report the mid-term results.

**Methods**

A total of 133 hips in 120 children aged less than two years who underwent closed reduction, with a minimum follow-up of five years or until subsequent surgery, were included in the study. The protocol defines the criteria for an acceptable reduction and the indications for a concomitant soft-tissue release. All children were immobilised in a short-leg cast for three months. Arthrograms were undertaken at the time of closed reduction and six weeks later. Follow-up radiographs were taken at six months and one, two and five years later and at the latest follow-up. The Tönnis grade, acetabular index, Severin grade and signs of osteonecrosis were recorded.

**Results**

A total of 67 hips (51%) were Tönnis grade 3/4 hips. By 12 months, 20 reductions (15%) had not been maintained, and these required open reduction. In all, 55% of these were Severin 1; the others were Severin 2, due to minor acetabular dysplasia. Of the 113 successful closed reductions, 98 hips (87%) were Severin 1. Surgery for residual DDH was offered for ten hips. Osteonecrosis was seen in 32 hips (29%) but was transient in 28. In total, two children (1.5%) had severe osteonecrosis. Bilateral dislocations were significantly more likely to fail and most Tönnis 4 hips failed.

**Conclusion**

Closed reduction, with concomitant adductor and psoas release when required and the use of a short leg plaster of Paris cast for three months, can produce good mid-term results in children with DDH aged less than two years. This protocol is not recommended for Tönnis 4 hips.

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Closed reduction is an accepted form of treatment for the children with developmental dysplasia of the hip (DDH) who have failed early splintage or presented late. The principles of treatment include gentle reduction achieving as stable and congruent a joint as possible. Soft-tissue contractures that interfere with obtaining or maintaining a reduction must be overcome so as to minimise the compressive or deforming forces on the vulnerable blood supply and cartilaginous structures.

Previous studies report variable mid- and long-term outcomes following closed reduction, with significant variations in technique. There is no consensus regarding the use of a soft-tissue release, the definition of an acceptable reduction, or the type and duration of post-operative immobilisation.

This study describes a standardised protocol for closed reduction, incorporating an open soft-tissue release when necessary, and using an above knee short-leg plaster of Paris (POP) cast. The aims were to assess: the effectiveness of this protocol in maintaining reduction, the resolution of acetabular dysplasia and the need for secondary bony surgery, the incidence and severity of osteonecrosis, and the radiological outcome as assessed by the Severin grading system at five years post-operatively and at maturity.
Patients and Methods
Case notes and radiographs were reviewed of all children with idiopathic DDH, who underwent a successful closed reduction at our institution between 2000 and 2010, with a minimum follow-up of five years. The indication for treatment was a subluxed or dislocated hip (Tönnis grades 2 to 4) in a child aged less than two years.

The Tönnis classification and the presence or absence of the ossific nucleus at the time of closed reduction were determined from radiographs. Arthrograms were reviewed to assess the appearance of the hip on the day of closed reduction and at the time of change of the POP cast six weeks later. Follow-up radiographs were analysed at six months, one, two and five years post-operatively and the following measurements noted: acetabular index (AI), signs of osteonecrosis and the Severin grade at six years of age and at the most recent follow-up. Osteonecrosis was classified using the Kalamchi and MacEwen group classification. The epiphyseal height to width index was measured on radiographs between 12 and 18 months post-operatively and at final follow-up. The height-to-width index of the femoral head as described by Casaletto et al. was used as a measure of its deformity following treatment, adapting Eyre Brook’s use of the index in Perthes’ disease (Table I).

Protocol for a closed reduction of a dislocated hip. An examination of the hip under anaesthetic and arthrogram were performed via a medial approach, using 2 ml to 3 ml of Omnipaque 240 or 300 (GE Healthcare, London, United Kingdom). An Ortolani manoeuvre was performed and the quality of reduction was assessed, including the arc of stability in flexion/extension, abduction/adduction and rotation. Medial pooling of < 3 mm was accepted provided that the maximum diameter of the femoral head was positioned under and in contact with the deformed labrum and in line with the triradiate cartilage (Fig. 1a). If the arc of abduction/adduction between redislocation and comfortable, gravity assisted, abduction was < 30° and/or abduction in 90° flexion was < 45°, an adductor longus release was performed. If the abducted hip was unstable in extension beyond 90° of flexion, the psoas tendon was released via a transverse groin incision at the lesser trochanter in the interval between adductor brevis and pectineus.

The hip(s) were held reduced whilst a short-leg cast was applied with the hips flexed to > 90° in comfortable, gravity assisted abduction. The cast was moulded around the greater trochanter and distal femur and did not extend below the knees, allowing free flexion and extension of the knee and rotation of the hip. Reduction was confirmed with a plain radiograph following application of the cast and with a limited cut CT scan two weeks later.

The cast was changed and an arthrogram was performed six weeks post-operatively in order to document the cartilaginous anatomy and the stability of the hip (Fig. 1b). If the hip was dislocated at either time, the cast was removed and an open reduction scheduled. The cast was replaced with a removable abduction brace three months post-operatively. This was worn for 23 hours a day for six weeks. Thus, treatment continued in total for 4.5 months.

Statistical analysis. This was performed using SPSS 11.0 (SPSS Inc., Chicago, Illinois) for Windows. Unless other...

Table I. The classification of osteonecrosis

<table>
<thead>
<tr>
<th>Group</th>
<th>Description</th>
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<tbody>
<tr>
<td>1</td>
<td>Changes affecting the ossific nucleus</td>
</tr>
<tr>
<td>2</td>
<td>Lateral physeal damage</td>
</tr>
<tr>
<td>3</td>
<td>Central physeal damage</td>
</tr>
<tr>
<td>4</td>
<td>Total damage to the head and the physis</td>
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CR, closed reduction
wise stated, categorical variables are expressed as proportions (%), and continuous variables are expressed as median (range). For categorical variables, differences between groups were assessed using the Pearson chi-squared test or two-tailed Fisher’s exact test. A p-value of ≤ 0.05 was considered statistically significant.

Results
During the study period, 152 hips in 137 children had a successful closed reduction. A total of 19 hips in 17 children were lost to follow-up and were excluded. A total of four of these moved country and two did not attend appointments after further surgery was advised (pelvic osteotomy; examination under anaesthesia and arthrogram). In the other 11 children, follow-up appointments were missed between the ages of two and five years. The demographics of the remaining 133 hips in 120 children are shown in Table II.

Early failure. Reduction could not be maintained in 13 of 133 hips (9.7%; 10/120 children): 11 were dislocated on the two week scan, having been located on the post-operative film. A total of two were reduced on the two week scan, but were markedly unstable with no improvement in the arthographic features at the time of the change of cast, six weeks post-operatively. The early failures included two children with bilateral DDH where one hip failed. A further seven hips (six children) required open reduction within 12 months of closed reduction for progressive subluxation. The initial arthograms were reviewed and all met the criteria of the protocol. Therefore, a total of 20 hips in 16 children failed after an initially acceptable closed reduction. This represents an overall rate of failure of 20 hips (of 133; 15%), and a rate of failure for unilateral hips of 10/107 (9%). All 20 failed hips underwent an open reduction. A total of 11 of these (55%) were Severin 1 at latest follow-up, the rest were Severin 2, due to minor acetabular dysplasia.

Factors associated with failure. A total of 15 of the 20 failed closed reductions were Tönnis grade 3 or 4. In all, five of six Tönnis grade 4 hips failed (p < 0.003). The only child with a Tönnis grade 4 hip which remained reduced had an acetabuloplasty when aged four years and requires a femoral osteotomy at six years of age. A younger age at the time of closed reduction was associated with failure; out of 106 hips that were 12 months or less at the time of closed reduction, 19 failed (18%), compared with one of 27 hips (4%) who were older than 12 months (p < 0.04). The AI at the time of closed reduction was not a significant factor. A total of 16/20 (80%) hips in which treatment failed had required a soft-tissue release, compared with 79 (70%) of those in whom treatment was successful (p = 0.54, not significant); this may reflect inherent instability in those in whom treatment failed.
Mid-term results. The 20 hips in 16 children which failed within 12 months were excluded, leaving 113 hips in 106 children for analysis (two had bilateral DDH with one hip in which treatment failed). In 47 hips, comparison arthrograms were not available for viewing, (although in all cases, the arthographic appearances at the six-week cast change had been recorded as satisfactory). A total of 48 arthrograms showed a good initial appearance. In 18 hips, arthrograms showed a dramatic improvement in appearance between the time of reduction and six weeks later. Figures 1a and 1b illustrate such a child. A total of seven hips in seven children (6%) were followed to skeletal maturity, 12 additional hips in 12 children (11%) were followed for more than ten years and the rest for more than five years.

Residual dysplasia. The AI decreased in all 113 hips. Further surgery was offered for ten hips (ten children) with an AI > 25° two to three years following closed reduction, with two undergoing two separate procedures, giving a rate of secondary surgery for residual DDH of 10%. A total of six required pelvic osteotomy, three femoral osteotomy and three both.

Final Severin grading. Of 113 hips, one (1%) is awaiting proximal femoral osteotomy for residual subluxation at six years of age, having had an acetabuloplasty two years previously (modified Severin grade 4, Fig. 2). All other hips were Severin grade 1 (98, 87%) or grade 2 (12%) at last follow-up. Of the 14 Severin 2 hips, eight had minor acetabular dysplasia, three had changes secondary to osteonecrosis and three had three adverse effects of both.

Osteonecrosis. Evidence of osteonecrosis was seen in 32 hips (29%) (Table III). In 28 (25%), this was “transient” (Kalamchi/McEwen 1) there was a minimal decrease in the height of the femoral head in ten of these at the latest follow-up. Of the 14 Severin 2 hips, two had minor acetabular dysplasia, three had changes secondary to osteonecrosis and three had evidence of both.

Severe osteonecrosis was seen in two children. In one, the ossific nucleus had been present at the time of closed reduction, and she had undergone a femoral and pelvic osteotomy for residual DDH when aged 2.5 years. Two children had Kalamchi and MacEwen group 2 lateral growth arrest.

Of the four hips with clinically significant osteonecrosis (Kalamchi and MacEwen groups 2 to 4), three occurred in hips where the ossific nucleus was present at the time of closed reduction. The prevalence of any degree of osteonecrosis was 15/59 (25%) in those with an ossific nucleus at the time of closed reduction, compared with 17/43 (40%) in those without (chi-squared test, not significant).

Epiphyseal height and width ratio. A low femoral head height-width ratio (< 0.357) between 12 and 18 months after closed reduction was seen in four hips, all of which showed evidence of transient osteonecrosis. A total of three had long-term evidence of a decrease in the height of the femoral head, although it affected the Severin grading adversely in only one (Fig. 3).

Of 17/113 (15%) hips which had a decrease in the height of the femoral head at final follow-up, only five were Severin 2 as a result. A total of ten had a low head height-to-width ratio at between 12 and 18 months after closed reduction; four had normal ratios without evidence of osteonecrosis.

Discussion
We have used a standardised protocol of closed reduction for the management of DDH in a child aged less than two years over a 15-year period. Our secondary rate of failure, defined as a failure to maintain an initially successful closed reduction was 15%. Most studies of closed reduction1-6 either do not comment on failure rates, or combine rates of primary failure (those in whom an initial adequate reduction is not obtained) with secondary rates: we believe that these represent two different issues, a failure to achieve an acceptable reduction versus a failure to maintain that reduction. One study reports a secondary failure rate of 6%.

Table III. Incidence and Kalamchi and MacEwen classification of osteonecrosis

<table>
<thead>
<tr>
<th>Type of osteonecrosis (total number of hips = 32)</th>
<th>Ossific nucleus present at the time of closed reduction</th>
<th>Soft-tissue release</th>
<th>Prior brace treatment</th>
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<tr>
<td>Transient n = 28 (%)</td>
<td>11 (39)</td>
<td>25 (89)</td>
<td>10 (36)</td>
</tr>
<tr>
<td>Type 2 n = 2 (%)</td>
<td>2 (100)</td>
<td>2 (100)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Types 3 and 4 (severe) n = 2 (%)</td>
<td>1 (50)</td>
<td>2 (100)</td>
<td>0 (0)</td>
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Fig. 3
Radiograph showing decreased height of the femoral head in a Severin 2 hip.
Low rates of secondary failure have been related to young age at the time of reduction, and to the congruency of the initial reduction. Our rate of secondary failure was not related to increased age at the time of closed reduction, as might be expected, but to a younger age. We have achieved successful reduction up to the age of two years. A total of five of six Tönnis 4 hips failed, with the other requiring secondary surgery. Although Tönnis 3 hips also had a higher rate of failure, 84% responded to the protocol. In bilateral DDH, the success rate is lower; however, when closed reduction is successful, the outcomes are as good as in unilateral cases.

It is accepted that the outcome is dependent on the quality of the initial reduction. Older studies differ from recent studies in their criteria for an acceptable closed reduction, recent studies accept only congruent reduction and minimal medial dye pooling. We do not require a perfect reduction arthrographically at the time of closed reduction. In some hips with medial pooling after reduction, the femoral head is resting against the posterior acetabulum due to a tight psoas muscle; psoas tenotomy improves this. Our protocol considers soft-tissue obstacles to the stability of the hip as well as the completeness of the reduction. Most authors only describe an adductor release.

During the first six weeks in the cast, the femoral head centralises as the labral shape changes and the concavity of the acetabulum increases (Fig. 1b). Only two other historical studies mention the use of a short-leg cast. There are significant practical advantages for the child and carer and we believe that the rotation allowed by the above knee cast allows the head to ‘settle’ into the acetabulum, producing the improvement in arthrographic appearance in the first six weeks. A quarter of hips showed a dramatic improvement in appearance during this time. These 18 out of 66 hips are likely to have undergone an open reduction in other centres where only a ‘perfect’ reduction is accepted. With our protocol, they had a good or excellent medium-term outcome.

The optimal time for immobilisation following closed reduction is not known, with prolonged periods of immobilisation being common. Some have used the resolution of dysplasia to guide duration.

We have shown good results with a standard period of immobilisation of three months in a cast followed by six weeks of abduction bracing, with resolution of dysplasia in 90% of hips and acceptable rates of failure and secondary surgery, at a minimum follow-up of five years. We believe that acetabular remodelling continues after the cessation of casting or bracing. We could not identify any factors affecting the rate of decrease in AI or the likely requirement for secondary surgery for residual DDH.

Our rate of secondary surgery for residual DDH compares favourably with other studies that quote rates of between 5% and 66%, without describing the criteria for secondary surgery. Almost 87% of hips were modified Severin grade 1 at the latest follow-up. Other series report Severin 3 and 4 hips in up to 60%. Our single Severin 4 hip is the only Tönnis 4 hip that had an initially successful closed reduction and was subluxed at six years of age; using our current protocol, this child would not now be considered suitable for closed reduction.

In ten of the 28 hips (25%) with group 1 osteonecrosis, which is often considered transient and inconsequential, there was permanent evidence of osteonecrosis manifested as decreased height of the femoral head at the latest follow-up, although it was only severe enough to affect the Severin grade in three hips. A total of 14 hips (12.5%) had evidence of some permanent change in the height of the femoral head.

Although there was a tendency for more group 1 osteonecrosis in those hips without an ossific nucleus at the time of closed reduction, three of our four children with groups 2, 3 or 4 Kalamchi and MacEwen (significant) osteonecrosis occurred in hips in whom the ossific nucleus was present at the time of closed reduction. Currently, the presence or absence of the ossific nucleus does not influence the timing of our closed reduction.

In this study, all but one hip with a femoral head height-to-width index < 0.357 at 12 to 18 months after closed reduction developed changes in the height of the femoral head in the mid- and long-term, despite having been graded as having ‘transient’ osteonecrosis. The epiphyseal height to width ratio may be a more sensitive determinant of significant osteonecrosis than other grading systems. However, four hips which had no evidence of osteonecrosis or a reduced head height-to-width ratio at between 12 and 18 months developed a subtle decrease in height of the femoral head later; this requires more evaluation.

We acknowledge that follow-up was not to skeletal maturity in most children. Group 2 osteonecrosis with a lateral physeal arrest presents during the adolescent growth spurt, and could affect the final Severin grade. However, we found that by using stringent criteria for the acceptance of a closed reduction, albeit one which may be incongruent, and with the use of an open soft-tissue release where necessary, good results can be obtained. We do not now advocate closed reduction for Tönnis 4 hips and we now treat these hips with an open anterior reduction at approximately 12 months of age.

Take home message:
Closed reduction can be successful under the age of two years in Tönnis 2 and 3 hips.

Author contributions:
S. J. Tennant: Data collection, Data analysis, Manuscript writing, Patient contribution.
D. M. Eastwood: Manuscript writing, Patient contribution.
P. Calder: Data collection, Data analysis, Patient contribution.
A. Hashemi-Nejad: Patient contribution, Manuscript editing.
A. Catterall: Development of technique, Manuscript editing.

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