CHILDREN'S ORTHOPAEDICS

Prognostic factors for premature growth plate arrest as a complication of the surgical treatment of fractures of the medial malleolus in children

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McFarland fractures of the medial malleolus in children, also classified as Salter–Harris Type III and IV fractures, are associated with a high incidence of premature growth plate arrest. In order to identify prognostic factors for the development of complications we reviewed 20 children with a McFarland fracture that was treated surgically, at a mean follow-up of 8.9 years (3.5 to 17.4). Seven children (35%) developed premature growth arrest with angular deformity. The mean American Orthopaedic Foot and Ankle Society Ankle-Hindfoot Scale for all patients was 98.3 (87 to 100) and the mean modified Weber protocol was 1.15 (0 to 5). There was a significant correlation between initial displacement (p = 0.004) and operative delay (p = 0.007) with premature growth arrest. Both risk factors act independently and additively, such that all children with both risk factors developed premature arrest whereas children with no risk factor did not. We recommend that fractures of the medial malleolus in children should be treated by anatomical reduction and screw fixation within one day of injury.

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Physial injuries of the ankle are second in frequency to those of the distal radius and carry a high risk of complications.1 In particular, injuries of the distal tibial physes have a greater risk of premature growth plate arrest with angular deformity, early degenerative changes and leg length discrepancy than previously thought. Whereas earlier studies reported an overall incidence of physeal complications of between 2% and 14%,6,9,17 later reports showed an incidence of between 39.6% and 67% for Salter–Harris type II, between 13% and 21.7% for type III and between 13% and 20% for type IV fractures.6,9

In 1931 McFarland described physeal fractures involving the medial malleolus and the subsequent deformities.7 In 1936, Aitken defined two types of these injuries corresponding to Salter-Harris type III and IV fractures, and suggested that a crushing injury caused partial growth arrest.8 Since then, many contributing factors have been described, including the mechanism of injury, the initial displacement, the number of attempts at reduction, closed or open reduction and residual displacement.4,6,9,12 However, premature growth arrest is unpredictable and can occur without any initial displacement.13 In animal studies, periosteal interposition within the physeal fracture can cause growth plate arrest by stimulating the development of bone, fibrocartilage or fibrous tissue,14,15 and most clinical studies emphasise the importance of anatomical reduction.5,6,9,10 Traditionally, open reduction was thought to be a risk factor for growth arrest,16 but it is currently thought that anatomical reduction prevents physeal complications.5,9,17

In this study we reviewed 20 patients who were treated operatively for Salter-Harris type III and IV McFarland fractures of the medial malleolus in order to identify factors leading to physeal complications.

Patients and Methods

We reviewed the notes and radiographs of 20 children who underwent either closed reduction and percutaneous fixation or open reduction and internal fixation for a McFarland fracture in our institution between 1993 and 2009. There were 14 boys and six girls with a mean age at operation of 11.5 years (8 to 15) and a mean weight of 44.1 kg (30 to 82). The recorded data also included the mechanism of injury, Salter-Harris classification, associated injuries, time from injury to operation and method of fixation. All the injuries were closed and the operations were performed by four surgeons (including author DVP and senior author JNA). The radiological data included pre-operative, immediate post-operative and follow-up radiographs at six, 12, 24 and 48 weeks, and longer if there were...
complications. The initial and post-operative displacement was measured in millimetres as the largest distance between the epiphysis and the metaphysis on anteroposterior (AP) or lateral radiographs.

The mean clinical and radiological follow-up was 8.9 years (3.5 to 17.4). The patients were assessed according to the American Orthopaedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot Scale18,19 and the modified Weber protocol.20-22 The radiological assessment included the incidence of premature growth plate arrest, angular deformity, joint line irregularity, and tibial and fibular union. The angular deformity of the ankle mortise was measured using a line drawn parallel to the tibial plafond and a second drawn parallel to the tibial shaft, based on AP or lateral radiographs. Joint line irregularity was defined as any deviation from the normal ‘straight’ appearance of the distal tibial plafond by two authors (MK, DVP).

**Statistical analysis.** In order to address the hypothesis that each of the independent predictors has a significant discriminating power for the prediction of growth arrest, receiver-operating characteristics (ROC) curves were used. The ROC analysis also addresses another important issue: for each independent predictor it provides the cut-off value that yields the best trade-off between sensitivity and specificity.

Fisher’s exact test and 95% confidence intervals (CI) were used to verify the relationship between growth arrest and initial displacement and pre-operative delay. A p-value of < 0.05 was considered to be statistically significant.

**Results**

There were eight children with Salter-Harris type III and 12 with type IV fractures. A total of 11 children had associated fibular fractures (four with Salter-Harris type III and four with type IV fractures). Three children with type IV fractures and an associated fibular fracture presented with dislocation of the ankle, and one with a type III fracture had a fracture of the talus and dislocation of the ankle. The mean initial displacement was 7.05 mm (2 to 25) for all fractures, 6.12 mm (4 to 10) for Salter-Harris type III and 7.66 mm (2 to 25) for type IV fractures.

A total of 14 children underwent surgery within 24 hours, two on the second day, two on the third, one on the seventh and one on the 11th.

Of the eight children with Salter-Harris type III fractures, one underwent closed reduction and seven an open reduction. Similarly, only two of the 12 with Salter-Harris type IV fractures had a closed reduction. Cannulated, partially threaded cancellous screws were used in seven children (four Salter-Harris type III and three type IV fractures) and Kirschner (K)-wires in 13. Washers were used in three children. The mean residual displacement for all fractures on the immediate post-operative radiographs was 1.1 mm (0 to 2). The mean residual displacement was 1.16 mm (0 to 2) for Salter-Harris type III fractures and 1.0 mm (0 to 2) for type IV fractures. Metalwork was removed at a mean of 40 days (35 to 45) post-operatively for the K-wires and 11.9 months (2 to 22) for the screws.

Seven children (35%; three Salter-Harris type III and four type IV fractures) had premature growth plate arrest, all with an angular deformity of the ankle joint. Six had a varus deformity (2° to 17°), one of whom had an anterior tilt of the distal epiphysis of 22° in addition to a varus deformity of 2°, and one with a Salter-Harris type III fracture had a valgus deformity of 4°.

Five of the six children whose operation was delayed beyond 24 hours developed premature arrest, and six of the seven children with premature arrest had an initial displacement of > 6 mm. All seven had adapted well to the deformity and none had sought further surgery. Nevertheless, three children continue to be reviewed in case they need corrective surgery.

Six children (30%), three with a Salter-Harris type III fracture had joint line irregularity, but only three had an additional angular deformity (two with a Salter-Harris type III fracture and one with a type IV fracture). One child with a Salter-Harris type IV fracture and an intact fibula had delayed union of the distal tibia but no growth arrest (Figs 1 to 3).

The mean AOFAS Ankle-Hindfoot Scale for all children was 98.3 (87 to 100); 98.4 (87 to 100) for Salter-Harris type III fractures and 98.2 (93 to 100) for type IV fractures. The mean modified Weber protocol was 1.15 (0 to 5) for all children; 1.12 (0 to 3) for Salter-Harris type III fractures and 1.16 (0 to 5) for type IV fractures. In the seven children with premature arrest, ROC analysis showed that the initial displacement and pre-operative delay had a significant discriminating power for the prediction of growth arrest (p = 0.011 and p = 0.022, respectively) (Fig. 4). The best cut-off values were 6 mm for initial displacement and 0 days (within 24 hours) for pre-operative delay.

There was a significant relationship between growth arrest, initial displacement (p = 0.004) and pre-operative delay (p = 0.007, Fisher’s exact test).

The 95% CIs of the relative risk for initial displacement were 1.3 to 61.3, indicating that the probability of growth arrest in children with significant (> 6 mm) initial displacement is nine times greater than with an initial displacement ≥ 6 mm. The 95% CIs of the relative risk for pre-operative delay were 1.5 to 22.1, which means that the probability of growth arrest in children with significant pre-operative delay (> 24 hours) is almost six times (5.8) that of those in whom the operation is undertaken within 24 hours.

The initial displacement and pre-operative delay are independently and additively significant in the prediction of the outcome, each carrying its own weight of information in the prediction.

There were ten children with neither of the risk factors and none had growth arrest. Three of the six children with one risk factor and all four with both risk factors developed premature growth arrest.
Only two (18.2%) of the 11 children with a residual displacement of < 1 mm developed growth arrest, compared with five of nine (55.6%) with a residual displacement of 2 mm. However, this trend was not statistically significant (p = 0.160).

Discussion

Only 6% of tibial fractures in children involve the ankle-joint. McFarland fractures account for approximately 25% of distal tibial physeal injuries, and are reported to cause disturbance of growth in 13% to 50% of cases. The incidence in our children was 35%.

McFarland fractures with an initial displacement of > 2 mm are considered at high risk of premature growth arrest, but no significant correlation had been found until the study of Leary et al. We confirmed this correlation and identified a nine fold probability of growth arrest in children with initial displacement of > 6 mm. Consequently, in our opinion, all children with a significant initial displacement need to be reviewed until maturity.

Repeated attempts at closed reduction increase the incidence of premature growth arrest, and some have recommended proceeding directly to open reduction, even for fractures with minimal displacement.

Figure 1a
Radiographs of a Salter-Harris type IV McFarland fracture in an eight-year-old female patient, a) pre-operatively, showing initial displacement of 3 mm and a Salter-Harris type I fracture of the fibula, b) immediately post-operative after open reduction and fixation with two Kirschner wires, showing residual displacement of 2 mm, and c) at 16.7 years post-operatively, showing an excellent radiological result.

Figure 1b

Figure 1c

Figure 2a
Radiographs of a Salter-Harris type IV McFarland fracture in a 14-year-old male patient, a) pre-operatively, showing initial displacement of 8 mm and a Salter-Harris type I fracture of the fibula, b) immediately post-operative after open reduction and fixation with a cannulated cancellous screw, showing residual displacement of 2 mm, and c) at 6.8 years post-operatively, showing partial inner growth plate arrest and 17° varus angulation.
with initial displacements of 3 mm, 4 mm and 4 mm, respectively, had a closed reduction as the choice of the treating surgeon. Otherwise, open reduction was performed without any attempt at closed reduction.

Pre-operative delay has hitherto not been reported to be associated with premature growth arrest. Five of the six of our children whose treatment was delayed beyond 24 hours developed growth arrest, and we found an almost six fold probability of growth arrest compared with those treated within 24 hours. We cannot explain why delay causes growth arrest. It may be that early surgery prevents the rapid development of fibrous tissue in the distal tibial physis, but experimental studies would be needed to confirm this hypothesis.

With regard to anatomical reduction and residual displacement, there are reports that displacement $\leq 2$ mm is acceptable.\textsuperscript{13,27} Most authors, however, believe that residual displacement predisposes to growth arrest, but this has not been proved statistically.\textsuperscript{9,10,17} Others have simply shown a trend between increased residual displacement and premature arrest.\textsuperscript{5,9} We also demonstrated such a trend and believe that anatomical reduction of the McFarland fracture should always be the goal.

Cottalorda et al\textsuperscript{9} proposed that although a fracture may appear to be well reduced fluoroscopically, it might not be reduced perfectly under direct vision as there may remain an undetected gap in front of or behind the plane of the screw. Conversely, Duran et al\textsuperscript{28} undertook percutaneous screw fixation of McFarland fractures in 12 children using intra-operative arthrography and recorded no cases of premature growth arrest. They recommended closed reduction and arthrography as a safe alternative to open reduction in selected cases. We performed open reduction in all but three of our patients. We do not believe that closed reduction is as successful as open, but were unable to prove this statistically. Unlike Cottalorda et al\textsuperscript{9}, we consider that arthrotomy should be carried out only in selected cases, as open reduction, removal of interposed tissue and compression of the fracture should be adequate in most cases.

Most surgeons use a cancellous screw to achieve compression and occasionally augment this with a washer, whereas others prefer K-wires to stabilise the fracture.\textsuperscript{23} We found no difference between screws and K-wires on the

![Fig. 3a](image1.png)  ![Fig. 3b](image2.png)  ![Fig. 3c](image3.png)

Radiographs of a Salter-Harris type III McFarland fracture in a nine-year-old female patient, a) pre-operatively, showing initial displacement of 9 mm and a Salter-Harris type I fracture of the fibula, b) immediately post-operative after open reduction and fixation with a cancellous screw and washer, showing 2 mm residual displacement and a retrograde intramedullary Kirschner wire for fixation of the fibular fracture, and c) at 6.6 years post-operatively, showing partial inner growth plate arrest and 2° varus angulation.

![Fig. 4](image4.png)

Receiver-operating characteristics (ROC) curves. Both the pre-operative delay and initial displacement have a significant discriminating power for the prediction of growth arrest ($p = 0.022$ and $0.011$, respectively) for pre-operative delay $0.819$ ($p = 0.022$) and initial displacement $0.852$ ($p = 0.011$).
final outcome. The use of a washer is controversial,9,28 as it could theoretically damage the peri-chondral ring and cause a physeal bridge. Although we did not encounter this problem, we no longer use washers.

Degenerative changes may result from chondral damage at the time of injury or articular incongruity.29 Long-term studies are conflicting. Whereas Caterini et al26 identified eight of 68 patients (12%) with osteoarthritis and a statistical correlation to both initial and residual displacement in a series with a mean follow-up of 27 years, others showed no evidence of osteoarthritis at 13 and 12 years post-operatively,27,30 in spite of displacement or growth arrest. Three of our patients with growth arrest had an irregular joint line with no correlation with the functional outcome, and we would need longer follow-up to identify the development of osteoarthritis in those patients.

In conclusion, we advise operative treatment of Salter-Harris type III and IV fractures involving the medial malleolus with an initial displacement of > 1 mm. No attempt at closed reduction should be performed pre-operatively. These children should undergo surgery either on the day of or the day after the injury. Those with an initial displacement of > 6 mm should be reviewed until maturity, especially if there has been pre-operative delay.

Supplementary material

Three tables, detailing i) the demographics and ii) the clinical and radiological outcomes of all 20 patients, and iii) the relationship between risk factors and growth arrest, are available with the electronic version of this article on our website www.bbj.boneandjoint.org.uk

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