OPEN FRACTURES OF THE ARM IN CHILDREN

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We describe the results of treatment of open fractures of the humerus, radius and ulna in 61 children. Most were due to low-energy trauma and were rarely associated with head or other injuries; 72% were Gustilo type I, 15% type II and 13% type III.

Fifteen children (25%) had open diaphyseal, supracondylic or T-shaped fractures of the humerus. Arterial injuries occurred in two (13%) and nerve injuries in 7 (47%). All nerve injuries recovered spontaneously. The long-term results in 13 children were excellent or good in 11 (85%) and fair in two (15%).

Forty-six children (75%) had open forearm fractures. Arterial injuries occurred in one (2%), nerve injuries in five (11%) and a compartment syndrome in five (11%). Ruptured radial and ulnar arteries and median and ulnar nerves were repaired in one child. All other nerve injuries resolved spontaneously. Early compartment release in five children prevented Volkmann's ischaemic contracture.

Normal union occurred in only 36 children (78%). Delayed union, nonunion, malunion and refracture frequently complicated type-II and type-III fractures of the shafts of the radius and ulna. The long-term results in 38 children were excellent or good in 33 (87%), fair in 4 (11%) and poor in one (2%).

The short-term results for open fractures of the humerus were better than for open fractures of the forearm, but the long-term results were similar being excellent or good in 86% of the children.

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Open fractures of the arm are uncommon in childhood. Davis and Green (1976) described only three cases in 547 children with fractures of the forearm and Pirone, Graham and Krajbich (1988) found only four in 230 children with supracondylar fractures of the humerus. Too few cases have been published for any conclusions to be made about the characteristics and treatment of such fractures. It is unclear whether they behave like their closed counterparts or whether they have, like open fractures of the leg, a high rate of early and late complications (Buckley et al 1990; Cramer, Limbird and Green 1992; Hope and Cole 1992).

We have reviewed 61 children with open fractures of the arm to determine the patterns of injury and the early and late results in comparison with those reported for closed fractures of the arm and open fractures of the leg.

PATIENTS AND METHODS
We reviewed all children with open fractures of the scapula, clavicle, humerus, radius or ulna who had been treated at The Hospital for Sick Children between May 1980 and December 1990. The injuries had been sustained at least three years before assessment; remodelling of such fractures is complete within this period (Flynn, Matthews and Benoit 1974; Fuller and McCullough 1982). Open fractures of the wrist and hand were excluded; they have been discussed previously (Barton 1979; Swanson, Szabo and Anderson 1991).

We treated 61 children (39 boys and 22 girls) with a mean age of nine years (4 to 15). The injuries had been caused by falls (36), playground accidents (16) and motor-vehicle accidents and other causes (9).

The sites of the fractures are shown in Table I. There were no open injuries of the scapula, clavicle or proximal humerus. Fifteen (25%) of the open fractures were in the

<table>
<thead>
<tr>
<th>Site</th>
<th>Number of children</th>
</tr>
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<tbody>
<tr>
<td>Humerus</td>
<td></td>
</tr>
<tr>
<td>Shaft</td>
<td>3</td>
</tr>
<tr>
<td>Supracondylic</td>
<td>9</td>
</tr>
<tr>
<td>Supracondylar with intercondylar extension</td>
<td>3</td>
</tr>
<tr>
<td>Forearm</td>
<td></td>
</tr>
<tr>
<td>Proximal</td>
<td>4</td>
</tr>
<tr>
<td>Middle</td>
<td>28</td>
</tr>
<tr>
<td>Distal</td>
<td>14</td>
</tr>
</tbody>
</table>

Table I. Sites of open fractures of the arm in 61 children

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humerus and 46 in the forearm. We used the Gustilo classification to describe the severity of the open fractures (Gustilo and Anderson 1976), and most of the injuries were type I (Table II).

**Treatment.** Initial treatment included splintage, analgesia and tetanus prophylaxis. Antibiotic cover was provided by cephalosporin for type-I and type-II fractures with the addition of an aminoglycoside for type-III injuries. Penicillin was also used in ten children whose wounds were contaminated with soil.

We performed debridement within 12 hours of the injury. Fractures of the humeral shaft were reduced and immobilised with a plaster slab (1 case) or with intramedullary rods and a plaster slab (2 cases). All supracondylar fractures of the humerus were reduced and stabilised by percutaneous crossed Kirschner wires (Pirone et al 1988). T-shaped distal humeral fractures were fixed by Kirschner wires (1 case) or with screws and plates (2 cases). For all distal humeral fractures, the elbow was held in approximately 70° of flexion with a plaster slab.

Forearm fractures were stabilised by plaster casts alone (21 cases), intramedullary rods (12), plates and screws (9), percutaneous Kirschner wires (3) or an external fixator (1) (Figs 1 and 2). Fractures which were internally fixed were also supported in a plaster cast.

The wounds were treated by delayed primary suture or skin grafting. Split-thickness skin grafting was used when there was real or apparent skin loss and whenever fasciotomies were performed. No free microvascular flaps were required.

**Table II.** Gustilo severity grading of 61 fractures of the arm, by number and percentage

<table>
<thead>
<tr>
<th>Grading</th>
<th>Humerus (n = 15)</th>
<th>Forearm (n = 46)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>9</td>
<td>60</td>
</tr>
<tr>
<td>II</td>
<td>4</td>
<td>27</td>
</tr>
<tr>
<td>III</td>
<td>2</td>
<td>13</td>
</tr>
</tbody>
</table>

**Early assessment.** For early assessment, infection was diagnosed clinically and confirmed by culture. The fracture was judged to be clinically united when it was no longer mobile or tender, and radiologically sound when it was bridged by callus or cortical bone (Buckley et al 1990). Delayed union was diagnosed when 12 weeks or more were required for union, and nonunion when fracture healing failed to progress after 12 weeks (Price et al 1990). Malunion of the humeral shaft was defined as residual angulation of more than 15° in any plane or more than 50% displacement. Malunion of the distal humerus was present if there was cubitus varus, extension deformity greater than 20° or a step in the joint surface (Flynn et al 1974), and of the radius and ulna if there was more than 10° of angulation, 50% of displacement, any malrotation, or encroachment of the interosseous membrane (Price et al 1990).

**Late assessment.** We reviewed 51 children (84%) at 3 to 13 years after their injury. Pain, appearance, and function were assessed by questionnaire. Limb alignment, range of motion, scarring, perfusion and neurological function were evaluated clinically. Alignment, remodelling and physeal...
Radiographs of the forearm of an 11-year-old boy with a type-IIIC fracture (a,b). There was extensive soft-tissue damage (see text). Dynamic compression plating was undertaken after shortening of the radius and ulna of 3 cm. An iliac-bone graft of the nonunited fracture of the ulna was performed seven months later (c,d). Four years later he had acceptable union, mild pain with major activities, and a fair result (e to h).

damage were judged from radiographs.

The final clinical outcome of the forearm fractures was graded as excellent if there were no complaints on strenuous physical activity and loss of less than 10° of forearm rotation, good if there were mild complaints on strenuous physical activity or loss of 11° to 30° of forearm rotation, fair if there were mild subjective complaints during daily activities or loss of 31° to 90° of forearm rotation, and poor if the outcome was worse than this (Daruwalla 1979; Grace and Eversmann 1980; Price et al 1990). The final outcome of the humeral fractures was graded according to the carrying angle and range of motion of the elbow (Flynn et al 1974).

RESULTS

Fractures of the humerus. Arterial injuries were present in two children with supracondylar fractures of the humerus
Table III. Early complications and outcome of 61 fractures of the arm, by number and percentage.

<table>
<thead>
<tr>
<th>Early outcome</th>
<th>Humerus (n = 15)</th>
<th>Forearm (n = 46)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial injury</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>Nerve injury</td>
<td>7</td>
<td>47</td>
</tr>
<tr>
<td>Compartment syndrome</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Infection</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Normal union</td>
<td>15</td>
<td>100</td>
</tr>
<tr>
<td>Delayed union</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Nonunion</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Malunion</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Refracture</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Growth arrest</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

In one, the brachial artery was intact but pulseless. Vascular repair was not undertaken as the limb was well perfused and the pulse returned to normal over the following few months. In the other, the brachial artery was also intact but pulseless. Limb perfusion was inadequate so resection and vein grafting were performed. At late review, both children had normal perfusion of their injured limbs.

Nerve injuries occurred in seven children (47%) (Table III). One child with a fracture of the humeral shaft had a radial-nerve palsy. The nerve was explored as part of the wound debridement. It was intact and normal function returned within a few months. The supracondylar and T-shaped condylar fractures were associated with three cases of median nerve palsy and one each of ulnar, combined median and ulnar, and combined radial and ulnar nerve palsies. The median nerves were explored and found to be intact in the two children with arterial injuries. The nerves were not explored in the other six children. At late review, all children had normal nerve function.

Fracture union was normal and there were no compartment syndromes or infections (Table III).

At late review, all children with supracondylar fractures of the humerus or fractures of the shaft of the humerus had excellent or good results (Table IV). Two with T-shaped condylar fractures of the distal humerus had poor results because of fixed-flexion deformities of the elbows. One of these children also had poor scars.

Fractures of the forearm. There were nerve injuries in 11% of the children (Table III). There were three median nerve palsies and two combined median and ulnar nerve injuries, all of which recovered spontaneously except in one child with a severe degloving injury of the forearm (Fig. 2). In this case median and ulnar nerves and radial and ulnar arteries were ruptured. They were repaired primarily with restoration of normal circulation and recovery of good motor and sensory nerve function. Multiple ruptured tendons were also repaired.

Compartment syndromes occurred in 20% of the children with fractures of the midshafts of the radius and ulna. Early fasciotomies of the anterior compartments of the forearm prevented Volkmann’s ischaemic contracture.

The proximal fractures were type-I injuries and were treated with casts (2 cases) or intramedullary rods (2 cases). The distal fractures included 11 type-I, two type-II and one type-III injury. They were treated with casts (10), intramedullary rods or Kirschner wires (3) or plates (1). Normal union occurred in all children with proximal and distal fractures of the forearm (Fig. 1).

The mid-forearm fractures were treated by cast (9), intramedullary rods or Kirschner wires (10), plates (8) or external fixation (1). Uncomplicated fracture union occurred in 16 of the 20 children with type-I injuries of the midshafts of the radius and ulna.

Malunion, refracture or both occurred in the other four children. In one, malunion of the fracture was still present two years later when refracture was caused by another fall. In another, malunion persisted but without refracture. In the third, refracture occurred within a month of removal of the cast and intramedullary rods. The fracture was well aligned and appeared to be healing normally. In the fourth, dynamic compression plates were removed 22 months after the injury and the radius fractured through a screw hole five months later.

There was normal union in only two of the eight children with type-II or type-III injuries of the midshafts of the radius and ulna. Two required plating and bone grafting for nonunion, two had malunion, one had delayed union, and one had delayed union with malunion and refracture through a screw hole in the radius.

Overall, complications in fracture healing occurred in ten of the 28 children (36%) with fractures of the midshafts of the radius and ulna.

At late review, 87% of the children with forearm fractures had excellent or good results (Table IV). Those with fair and poor results had the most severe midshaft injuries. Those with fair and poor results showed loss of forearm rotation and discomfort in use. There was extensive scarring in six children, and three had painful neuromata of subcutaneous nerves.

DISCUSSION

Most open fractures of the arm resulted from low-energy trauma and were rarely associated with head or other
injuries. Type-I open fractures were five times as common as type-II fractures. Type-III fractures were due to high-energy trauma with vascular and severe soft-tissue injuries.

We saw no open fractures of the clavicle, scapula or proximal humerus. The shaft and distal humerus were involved in 25% and the radius and ulna in 75%. The fracture patterns were similar to those observed in closed fractures of these bones (Davis and Green 1976; Flynn et al 1974).

Injuries to the brachial artery and nerve injuries were common with fractures of the humerus, but the injured arteries were found to be in continuity when they were explored during debridement of the overlying wound. Vascular repair was undertaken only if there was poor distal perfusion. Injured nerves were explored only if they were in the wound. All were found in continuity and all nerve injuries, whether explored or not, recovered spontaneously. No additional incisions were needed to explore injured nerves.

All fractures of the shaft and distal end of the humerus healed normally. Despite accurate reduction, two of the three children with T-shaped fractures of the distal humerus had some permanent elbow stiffness, probably due to fibrosis from the injury and surgery (Hohl 1976).

None of the children with humeral fractures had a compartment syndrome or Volkman’s ischaemic contracture. Their absence was probably due to the routine use of posterior plaster slabs to hold the elbow in approximately 70° of flexion. In this position the anterior soft tissues, including the vessels, are not compressed. All supracondylar fractures of the humerus were reduced and cross-pinned with Kirschner wires so that the elbow could be immobilised in this position (Flynn et al 1974).

Neurovascular injuries were less common in the forearm than in the humerus. Arterial injuries were rare but when they did occur the vessels were ruptured and needed to be repaired to restore normal perfusion. Nerve palsies associated with arterial injuries were due to rupture of the nerves. In the absence of arterial injuries, however, all nerve palsies resolved spontaneously. Injured nerves need not be explored if they are not in the wound and not associated with arterial injuries.

There was a compartment syndrome in approximately 20% of the children with open fractures of the mid-forearm, but this is not sufficiently frequent to warrant routine compartment release in all cases, particularly as it requires an incision left open from the elbow to the wrist. Measurement of the compartment pressures during and after the debridement is probably better, so that fasciotomy is confined to those with abnormal pressures.

Fractures of the proximal and distal forearm healed well after cast immobilisation or fixation with intramedullary rods or Kirschner wires. In contrast, approximately one-third of the children with fractures of the mid-forearm had complications such as delayed union, malunion, refracture and nonunion. These were more common after type-II and type-III injuries as reported for open fractures of the tibia in childhood (Hope and Cole 1992).

Cast immobilisation is suitable for stable type-I fractures of the mid-forearm, but internal fixation is preferable for unstable fractures which include some type-I, most type-II and all type-III injuries. Fine intramedullary rods are a suitable method of fixation (Lascombes et al 1990). The ulna can be stabilised with a straight rod; a curved rod can be inserted into the distal radius, proximal to the growth plate, allowing the normal radial bow to be restored by rotation of the rod. The ends are sometimes left protruding through the skin for easy removal, but to avoid refraction it is preferable to bury them and remove them a year later (Lascombes et al 1990; Toussaint, Vanderlinden and Bremen 1991).

Plates have the advantage of providing rigid fixation but need larger incisions and more extensive dissection, and fractures may occur through screw holes. They are preferred for type-III injuries in which bone shortening is used to facilitate neurovascular repairs.

We used a half cast, then a complete cast, with all forms of internal fixation of forearm fractures to protect the healing soft tissues. After three weeks, the cast is removed, the arm is supported in a sling and movement is encouraged. When internal fixation is not used, a forearm cast-brace is required to reduce the risk of refraction after removal of the primary cast at 6 to 12 weeks after the injury.

We had no osteomyelitis in our study probably because of the thorough debridement within 12 hours of injury in all cases.

Poor scars were common, particularly after fractures of the forearm, and many required scar revision. Some will require tissue expansion to obtain sufficient skin to replace grafted areas (Cole et al 1990).

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

REFERENCES


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