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Clinical results of intramedullary nailing following closed or mini open reduction in pediatric unstable diaphyseal forearm fractures

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Objectives: We compared the clinical results of open reduction with a mini incision and closed reduction in pediatric unstable diaphyseal forearm fractures treated with intramedullary nailing.

Methods: We retrospectively evaluated 45 children who were treated with intramedullary nailing for unstable middle third diaphyseal forearm fractures. Before intramedullary nailing, 24 patients (group 1; 5 girls, 19 boys; mean age 10 years; range 5 to 14 years) underwent open reduction with a mini incision, and 21 patients (group 2; 5 girls, 16 boys; mean age 11.5 years; range 8 to 13 years) underwent closed reduction. There were 16 closed, seven Gustilo-Anderson type 1, and one type 2 open fractures in group 1, and 15 closed and six type 1 open fractures in group 2. The mean time to surgery was 5 days (range 1 to 20 days) in group 1, and 3.1 days (range 1 to 5 days) in group 2. Rush rods or Kirschner wires were used for fixation. In group 1, both radius and ulna were fixed in all the patients, whereas fixation involved both bones in 18 patients, and only ulna in three patients in group 2. Functional results were evaluated according to the criteria of Price et al. The mean follow-up period was 33 months (range 12 to 89 months) in group 1, and 37 months (range 14 to 52 months) in group 2.

Results: Union was obtained in a mean of 7.1±1.0 weeks (range 6 to 9 weeks) in group 1, and 6.5±1.0 weeks (range 6 to 10 weeks) in group 2. The implants were removed after a mean of 7.2±1.7 weeks (range 6 to 10 weeks) in group 1, and 8.1±0.4 weeks (range 8 to 10 weeks) in group 2. The two groups differed significantly with respect to union and implant removal times (p=0.036 and p=0.002, respectively). According to the criteria of Price et al., the results were excellent in 19 patients (79.2%) and 18 patients (85.7%), and good in five patients (20.8%) and three patients (14.3%) in group 1 and 2, respectively. There was no significant difference between the functional results of the two groups (p>0.05). Complications showed a similar profile in the two groups, being one major (4.2%) and seven minor (29.2%) in group 1, one major (4.8%) and eight minor (38.1%) in group 2. None of the patients had complications such as limb-length discrepancy, epiphyseal damage, angular or rotational deformity, synostosis, or limited elbow or forearm range of motion.

Conclusion: Closed reduction or open reduction with a mini incision before intramedullary nailing yield similar functional results, with a similar complication profile in the treatment of pediatric unstable diaphyseal forearm fractures.

Key words: Bone wires; child; fracture fixation, intramedullary/methods; radius fractures/surgery; ulna fractures/surgery.

Diaphyseal fractures of the forearm account for 6% to 10% of all pediatric fractures.[1] Unlike both-bone forearm fractures in adults, which are generally treated by open reduction and osteosynthesis with plate and screw fixation, 90% of pediatric forearm fractures are successfully treated conservatively by

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closed reduction and casting.[1-4] The remaining 10% are irreducible or unstable fractures,[4] of which treatment methods include closed manipulation and casting under general anesthesia, fixation with pins and plaster, closed or open reduction with a mini incision and intramedullary nailing, open reduction and osteosynthesis with plate and screw fixation, and external fixators.[2-9]

Intramedullary nailing has become popular in the treatment of pediatric diaphyseal forearm fractures due to several advantages such as maintenance of reduction, minimally invasive and relatively easy application, protection of bone alignment, and rapid bone healing.[1-3,10,11] Open reduction of pediatric unstable forearm fractures is controversial.[12,13] In this study, we compared the clinical results of open reduction with a mini incision and closed reduction in pediatric unstable diaphyseal forearm fractures treated with intramedullary nailing.

Patients and methods

In a retrospective design, we evaluated 45 children who were treated with intramedullary nailing in two different centers between 1999 and 2007 for unstable 1/3 mid-diaphyseal forearm fractures, and had adequate follow-up and complete medical records. Of these, 24 patients (group 1; 5 girls, 19 boys; mean age 10 years; range 5 to 14 years) underwent open reduction with a mini incision before intramedullary nailing, and 21 patients (group 2; 5 girls, 16 boys; mean age 11.5 years; range 8 to 13 years) underwent closed reduction (Fig. 1, 2). Rush rods or Kirschner wires (K-wire) of appropriate size were used in all the patients. In group 1, both radius and ulna were fixed in all the patients, whereas fixation involved both bones in 18 patients, and only ulna in three patients in group 2. None of the patients had associating injuries. Radial head fractures, pathological fractures, Galeazzi or Monteggia fracture-dislocations, 1/3 distal and proximal forearm fractures were not included.

The mechanisms of injury were as follows in group 1 and group 2, respectively: fall on the forearm (22 and 17 patients), assault and battery (2 and 2 patients), vehicle accident (1 and 2 patients). The mean time to surgery was 5 days (range 1 to 20 days) in group 1, and 3.1 days (range 1 to 5 days) in group 2.

Open fractures were evaluated according to the Gustilo-Anderson classification.[14] There were 16 closed, seven type 1, and one type 2 open fractures in group 1; and 15 closed and six type 1 open fractures in group 2.

Angulations in one of the two planes greater than 20 degrees in children younger than 10 years, and angulations greater than 10 degrees in children older than 10 years were defined as unacceptable and treated surgically.[6,15] Rotational deformities were also regarded as indications for surgical treatment.

Initially, closed reduction and long-arm casting were applied in all the patients in the emergency room. A subsequent attempt was made for closed reduction under general anesthesia and fluoroscopic control in cases in which the fracture could not be reduced initially or loss of reduction was observed during follow-up. Upon failure of these attempts, a decision for surgery was made. Open fractures were first handled with appropriate wound debridement and irrigation in the operating room, and unsuccessful attempts for closed reduction under fluoroscopic control resulted in a decision for surgery.

A pneumatic tourniquet was used in all the patients in group 1. In this group, first the ulnar fracture was reached through a dorsal mini incision about 3 cm in length at the level of the fracture. A K-wire or a Rush rod of appropriate diameter was inserted intramedullarly through the olecranon with the help of a hand perforator. After open reduction of the ulnar fracture, the intramedullary nail was advanced to the distal ulna to complete ulnar fixation, with special attention to avoid the K-wire protrusion to the distal ulnar epiphysis. Then, the radial fracture was exposed through a dorsal mini incision about 3 cm in length at the level of the fracture and a K-wire was advanced intramedullarly through the distal radial epiphysis. Following open reduction, the intramedullary nail was advanced to the proximal radius to complete radial fixation.

In group 2, following closed reduction, ulnar fracture was fixed with a K-wire or a Rush rod which was sent from the olecranon antegradely. In cases in which ulnar fixation was considered inadequate, radial fracture was also fixed with a K-wire or a Rush rod, of appropriate diameter, advanced through a drill hole just proximal to the distal radial epiphysis. In both techniques, Rush rods or K-wires were advanced as distal as possible of the ulna and as proximal as

Fig. 1. **(a)** An eight-year-old boy sustained a left forearm 1/3 mid-diaphyseal closed fracture after a fall on the forearm. **(b)** On the fourth day of admission, he underwent open reduction by mini incision and intramedullary nailing. **(c)** Follow-up radiographies two years after surgery and one year and ten months after implant removal. According to the Price criteria, the result was excellent.

possible of the radius and the distal ends of the pins were left outside the skin.

Postoperatively, a long-arm splint was used for six weeks in group 1, while a long-arm cast and short-arm cast were applied in group 2 for four and two weeks, respectively. Fracture union was defined as the appearance of an adequate callus formation at the fracture site on both anteroposterior and lateral radiographs together with a pain-free fracture site.

Complications requiring a subsequent intervention or the use of anesthesia that might affect long-term functional outcome, and iatrogenic problems related to implant use or insufficient manipulations were accepted as major complications, while those that were not important enough to affect long-term

Fig. 2. **(a)** A 13-year-old boy sustained a left forearm 1/3 mid-diaphyseal closed fracture after a fall on the forearm. **(b)** On the second day of admission, he underwent closed reduction and intramedullary nailing. **(c)** Follow-up radiographies four years after surgery and three years and ten months after implant removal. According to the Price criteria, the result was excellent.

prognosis or functional results were accepted as minor complications.[6]

Functional results were evaluated according to the criteria of Price et al.[16] based on the presence of pain and/or the degree of loss in forearm rotation. Thus, the absence of complaints with strenuous activity or loss of forearm rotation of less than 10 degrees or both showed an excellent result; the presence of mild complaints with physical activity or a rotational loss of 11 to 30 degrees showed a good result; a rotational loss of 31 to 90 degrees showed a fair result. All other conditions were considered to be a poor outcome. The mean follow-up period was 33 months (range 12 to 89 months) in group 1, and 37 months (range 14 to 52 months) in group 2.

Statistical analyses were made using the Yates' chi-square test (correction for continuity), Fisher's exact test, and Mann-Whitney U-test.

Results

There was no significant difference between the two patient groups with respect to gender (Yates' chi-square test, p=1.00). No statistical analysis was applied for the relation between etiological factors and types of fractures because of the small number of patients affected from an assault or vehicle accident and small number of patients with type 2 open fractures.

Union was obtained in a mean of 7.1±1.0 weeks (range 6 to 9 weeks) in group 1, and 6.5±1.0 weeks (range 6 to 10 weeks) in group 2. The implants were removed after a mean of 7.2±1.7 weeks (range 6 to 10 weeks) in group 1, and 8.1±0.4 weeks (range 8 to 10 weeks) in group 2. The two groups differed significantly with respect to union and implant removal times (Mann-Whitney U-test, p=0.036 and p=0.002, respectively).

According to the criteria of Price et al.,[16] an excellent result was achieved in 19 patients (79.2%) and 18 patients (85.7%), and a good result was achieved in five patients (20.8%) and three patients (14.3%) in group 1 and 2, respectively. There was no significant difference between the functional results of the two groups (Fisher's exact test, p=0.705).

In group 1, complications were major in one patient (4.2%) and minor in seven patients (29.2%). Major complication was a wrist drop deformity that developed postoperatively and resolved spontaneously six months after the operation. It was attributed to a radial nerve injury secondary to tourniquet use. As minor complications, three patients had decreased sensation resulting from irritation of the superficial radial nerve by the wire on the radial side. This problem resolved spontaneously within a mean of two months after the removal of the pins. Two patients had superficial skin infections at the incision site which were treated with appropriate wound care. One patient developed olecranon bursitis due to ulnar wire irritation, which resolved after the removal of the wire. In one patient, the radial wire migrated under the skin and was removed under local anesthesia in the outpatient setting.

In group 2, complications were major in one patient (4.8%) and minor in eight patients (38.1%). Union was delayed to the tenth postoperative week in one patent with an open fracture. As minor complications, one patient had painful olecranon bursitis due to ulnar wire irritation that resolved after the removal of the wire. One patient had decreased sensation due to the compression of the radial wire on the superficial radial nerve and it resolved spontaneously in three months. Two patients had ulnar neuropathies that resolved spontaneously. In four patients, the pins were removed due to disturbance under the skin or retrograde migration.

None of the patients had complications such as limb-length discrepancy affecting the upper extremity functions, epiphyseal damage, angular or rotational deformity, synostosis, or limited elbow or forearm range of motion.

Discussion

The initial treatment of pediatric forearm fractures should be closed reduction and casting.[5,17,18] However, this treatment is associated with loss of reduction and poor functional results in 5 to 7% of the patients.[3,4] Irreducible or unstable forearm fractures, on the other hand, are treated with several methods including closed manipulation and casting under general anesthesia, fixation with pins and plaster, closed or open reduction with a mini incision and intramedullary nailing, open reduction and osteosynthesis with plate and screw fixation, and external fixators.[2-9]

The clinical results of pediatric forearm fractures mainly rely on residual angulation at the fracture site, the presence of a rotational deformity, remodelling potential of the bone, the age of the patient, and the location of the fracture.[19,20] There is controversy on the degree of acceptable angulation after closed reduction and casting. Despite reports considering more than 20 degrees of angulation an indication for surgery in pediatric diaphyseal forearm fractures,[21] many studies recommend surgical intervention in the presence of more than 10 degrees of angulation following closed reduction.[1,7-9,16,19,22]

In a cadaver study, it was demonstrated that 10 degrees of angulation in 1/3 mid-diaphyseal forearm fractures did not restrict forearm rotational movements, whereas angulations exceeding 20 degrees were associated with at least 30% loss in forearm supination and pronation.[22] There is also no consensus on the degree of malrotation between the fractured bone fragments after closed reduction. Price et al.[16] reported that malrotations up to 45 degrees might be acceptable, whereas several studies indicated that malrotations in forearm fractures were unacceptable.[6,11,21,22]

In fractures with angular deformities, the amount of spontaneous remodelling is related to the age of the patient, degree of deformity, proximity of the fracture line to the physis, and the degree of radial and/or volar angulation.[11] After the age of 10 years, the remodelling potential of the bones decrease significantly.[4,9,16,18,23] For this reason, anatomic reduction is essential in children older than 10 years to avoid any restriction in forearm supination or pronation.[2] Treatment with closed reduction and casting in children older than 10 years has been associated with failure rates of up to 11%.[1] In the light of these data, we considered the age of the patient in relation to the degree of angulation in deciding in favor of surgical intervention. Thus, angulations greater than 20 degrees and 10 degrees were treated surgically in children younger and older than 10 years, respectively.

The localization of the fracture is another factor affecting the clinical outcome. It has been reported that middle third fractures cause more functional limitations compared to distal third diaphyseal forearm fractures.[6,19,24] A cadaver study showed that supination losses were much more obvious than pronation losses in middle third forearm fractures.[24]

Shoemaker et al.[10] suggested that the ideal mode of fixation of pediatric forearm fractures should maintain alignment, be minimally invasive and inexpensive, and carry an acceptable risk profile. Intramedullary nailing is a technique which meets these criteria. The main advantages of the technique include maintenance of reduction, provision of an inexpensive, minimally invasive, and relatively easy application, protection of bone alignment by three-point contact, acceleration of bridging callus formation through micromovements at the fracture site, and thus contribution to rapid bony healing.[1-3,6,8,10,11] Compared with open reduction and osteosynthesis with plate-screw fixation, intramedullary nailing causes less surgical morbidity, and implant removal is simpler.[1] Intramedullary fixation materials include Steinmann pins, K-wires, Rush rods, and elastic titanium nails.[3,6,9,10,17,25,26] In our study, we used Rush rods or K-wires of appropriate diameter for intramedullary nailing.

The use of open reduction in the treatment of pediatric unstable forearm fractures remains controversial.[12] It appears that many authors initially aim intramedullary nailing with the percutaneous technique in the treatment of pediatric forearm fractures, but then adopt mini open technique upon unsuccessful attempts of closed reduction.[2,6,8,10-13,17,18,23] It is known that the most common cause leading to failure of closed reduction is the interposition of the muscle bellies at the fracture site.[8,13] Yung et al.[8] recommended mini open reduction before intramedullary nailing in cases in which fracture translation exceeded 100%. Luhmann et al.[11] advocated that open reduction with a small incision would cause much less trauma to tissues than that caused by multiple reduction maneuvers. Pugh et al.[17] stated that casting would be adequate for immobilization, in place of intramedullary nailing, if closed reduction of fracture could be attained, but rotational stability would not be achieved in forearm fractures unless open reduction had been performed. Many studies have demonstrated that intramedullary nailing can be applied by the mini-open incision technique in pediatric unstable forearm fractures and that successful anatomic and functional results can be achieved with open reduction.[12,13,15,18,27] In our study, there were no significant differences between the functional results of patients treated with intramedullary nailing following closed reduction or open reduction by a mini incision. We believe that one of the major advantages of open reduction with the mini incision technique is that it obviates intraoperative use of fluoroscopy.

Compared to closed reduction, union takes a longer time after open reduction and internal fixation, regardless of the type of implant used.[28] We also found that union was achieved significantly earlier in patients treated with closed reduction and intramedullary nailing. However, considering that union time is, to some extent, a subjective criterion that depends on the interpretation of the evaluating physician, and that the difference between the two groups is quite small (~ 4 days) in this respect, it may be speculated that the longer union time associated with open reduction with a mini incision and intramedullary nailing may not have much clinical importance.

It is apparent in the majority of studies that, as a surgical technique for intramedullary nailing of the radius, the nail is sent through a cortical hole created just proximal to the distal radial physis, thus eliminating any adverse effect on the epiphyseal plate.[1-3,5,9,11,12,17,18,23,25,26] In contrast, some studies reported that the K-wire was inserted from the radial styloid and passed across the fracture site through the distal radial physis and this still caused no early premature closure of the growth plate.[8,10,29] In our study, we introduced the K-wire from the radial styloid passing through the distal radial epiphyseal plate in group 1, and through a cortical hole created just proximal to the epiphyseal plate in group 2. In neither of the conditions did we encounter any disturbance to the physis plate.

Complication rates following the treatment of pediatric unstable forearm fractures with intramedullary nailing have been reported as high as 50%.[2,4,8,11,17] Cullen et al.[2] reported a complication rate of 50%; notwithstanding, they obtained excellent or good clinical results in 95% of their patients. In another study, it was emphasized that, even though intramedullary nailing was associated with a higher complication rate than that of osteosynthesis with plate-screw fixation, the latter had a higher profile of major complications, whereas the majority of complications associated with intramedullary nailing resolved after implant removal.[4] In our study, complications were major in one patient (4.2%) and minor in seven patients (29.2%) in the group treated with open reduction by a mini incision, compared to one major (4.8%) and eight minor (38.1%) complications in patients treated with closed reduction. It was thought that the complications seen in patients treated with open reduction by a mini incision were not directly related to open reduction itself; rather, they were similar to those seen in patients treated with closed reduction and intramedullary nailing.

There is considerable diversity in the methods of forearm immobilization in the postoperative period. Some authors recommend immobilization for 2 to 8 weeks in the postoperative period,[8,10,11,17,18,26] whereas some emphasize the need for early mobilization and thus do not favor postoperative immobilization.[5,23] We used postoperative immobilization in both groups and none of the patients had limitations in elbow or forearm range of motion even though a special rehabilitation program was not applied.

Limitations of our study are its retrospective design and the small numbers of patients in the two treatment groups. Nonetheless, we feel that our findings would make a contribution to the literature in demonstrating the differences between the results of open and closed surgical approaches for pediatric unstable diaphyseal forearm fractures.

In conclusion, open reduction with a mini incision and intramedullary nailing is an easy, safe, and effective method in the treatment of pediatric unstable diaphyseal forearm fractures, whereby an anatomic reduction can be obtained under direct vision and without the need for intraoperative fluoroscopy, yielding similar functional results to those obtained by closed reduction and intramedullary nailing.

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