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ORIGINAL ARTICLE

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Occurrence and treatment of nonunion in long bone fractures in children

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Abstract *Background:* Because of favorable local biological factors, nonunion is rarely seen in long bone fractures in children, and there are few studies on pediatric nonunion in the literature. *Methods:* Twenty-six children under 15 years of age diagnosed with long bone nonunion were examined, and 19 received treatment. Patients with pseudarthrosis due to tumors or congenital causes were excluded from the study. The following factors were assessed for each patient: age and sex; cause, location, and type of fracture; form of initial treatment; incidence of infection and type of bacteria produced; time between fracture and diagnosis; and type of nonunion. *Results:* Twenty-two of the patients had fractures in the lower extremities, and 4 in the upper extremities. The femur was the most commonly affected bone (12 patients), followed by the tibia (10 patients). The average age of the patients was 9.6 years (range 1–15 years). The frequency of occurrence increased after the age of 6, and all patients but two were above this cutoff age. In each case, there was at least one factor contributing to nonunion, such as open reduction and insufficient fixation, open fracture, and infection. Of the 19 patients treated, 3 required reoperation. *Conclusion:* In our opinion, claims that pediatric nonunion is an extremely rare condition are exaggerated, and we do not agree that it is always due to an error in treatment. Nonunion does occur in children despite appropriate treatment, especially after the age of 6, and it may be resistant to therapy.

Keywords Children · Nonunion · Long bone fracture

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Introduction

The knitting of fractures is influenced by a number of mechanical and biological factors. The most important of the biological factors are microvascular circulation and osteoblastic activity, the former exerting an influence particularly in the hematoma organization and repair phases, and the latter in the cellular organization phase. In pediatric fractures, these local biological factors are in favor of knitting, and thus nonunion occurs rarely. Books on pediatric orthopedics make little or no mention of this complication. In the literature, nonunion is reported as a sporadic event among mature pseudarthrosis patients. Most cases reported involve patients over 10 years of age.

According to reports in the literature, nonunion in children may occur in fractures that are comminuted, associated with bone defect, accompanied by soft-tissue loss, infected, or treated with open reduction and internal fixation. It is claimed, however, that nonunion is exceedingly rare in children, even in the presence of these unfavorable factors, and that when it does occur, it is the result of a grave error in treatment. Levy et al. [6] reported that they encountered no cases of nonunion in 40 children, Bartlett et al. [2] the same in 23 children, and Song et al. [8] the same in 38 children, while Cullen et al. [3] reported only 1 case in 83 children with open fractures. In publications concerned with conservatively treated, closed pediatric fractures, nonunion is virtually never mentioned.

We encounter nonunion in children with a greater frequency than is indicated by other authors. In this study, we assess factors that contributed to nonunion in long bone fractures in children and the results of treatment.

Patients and methods

Twenty-six children less than 15 years old (17 boys and 9 girls) diagnosed with long bone nonunion were evaluated. Patients with nonunion due to congenital and tumor-related causes were excluded from the study. Patients with nonunion occurring after infection-related pathologic fractures were included. Only 11 of these patients received their initial treatment in our clinic. Thirteen

of the remaining patients were treated first in other clinics, and 2 had received primitive treatment.

Only patients whose X-ray series showed no progress in callus formation or fracture consolidation were included in the study. Patients showing progress but not at the desired rate were diagnosed with delayed union and were excluded from the study.

For each patient, age, sex, injury mechanism, place of fracture, type of fracture, and the initial type of treatment were determined. Additionally assessed were the time between the fracture and the diagnosis of nonunion, the presence of infection, and the types of microorganism produced, if any. We evaluated X-ray findings and classified the nonunion according to type using the system described by Weber and Cech [9].

Results

Twenty-two of the cases of nonunion were in the lower extremity and only 4 in the upper extremity. Femoral fractures were the most common (12 patients), followed by tibial (10 patients), isolated ulna (2 patients), isolated radius (1 patient), and radius-ulna fractures (1 patient) (Fig. 1). In those patients with nonunion isolated in the radius and in the ulna, both of the forearm bones had been broken, but only one had knitted.

The youngest patient was 1 year old and the oldest was 15, the average age being 9.6 years. In terms of age distribution, only 2 of the patients were younger than 7, and from this age the distribution was at close intervals (Fig. 2). The youngest patient had been injured while only 8 months of age, also suffering damage to the n. ischiadicus (Fig. 4A). The average age of patients with nonunion after open fractures was 8.1 years (range 1–12 years), that of patients with nonunion after closed fractures was 10.5 years (range 5–15 years), and that of patients with nonunion after osteomyelitis-related pathologic fractures was 8 years (range 5–11 years).

The causes of injury in 16 of the patients were high-energy traumas such as motor vehicle accidents, high falls, and high-velocity gunshot injuries (Fig. 4A). Ten patients suffered fractures in simple falls; 7 of these fractures were associated with osteomyelitis.

Open reduction with internal fixation was used in the initial treatment of the 11 closed fractures that were not associated with osteomyelitis; the fixation material used was intramedullary nails in 2 patients and plates with screws in 9. Ten of these closed fractures were in the femur and 1, in the tibia. Five patients underwent open re-

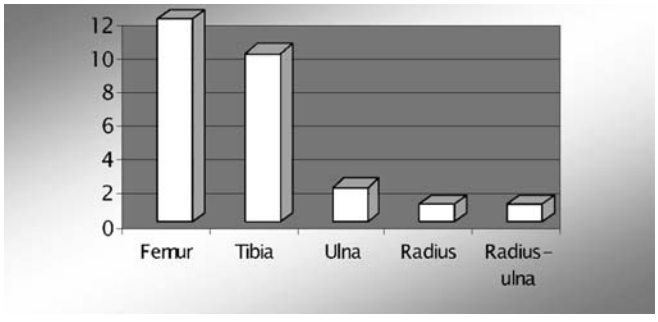

Fig. 1 Location of nonunion in children

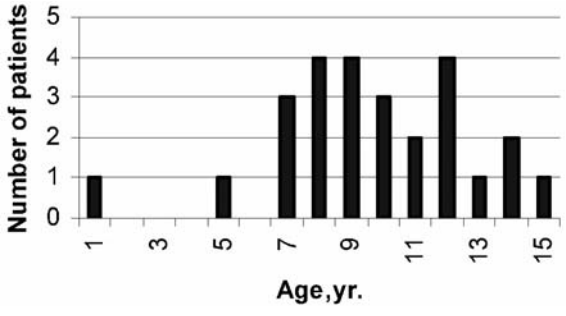

Fig. 2 Children's age at time of fracture

Fig. 3 **A** Defective nonunion of the right radius and ulna in a 12-year-old girl after pathologic fracture due to osteomyelitis. She underwent primitive treatment 4 years ago. **B** Fibular autograft and T-plate applied, but union was not achieved at the carpal level. Iliac bone grafts repeated 6 months later. **C** Postoperative 18 months later, radiograph shows union

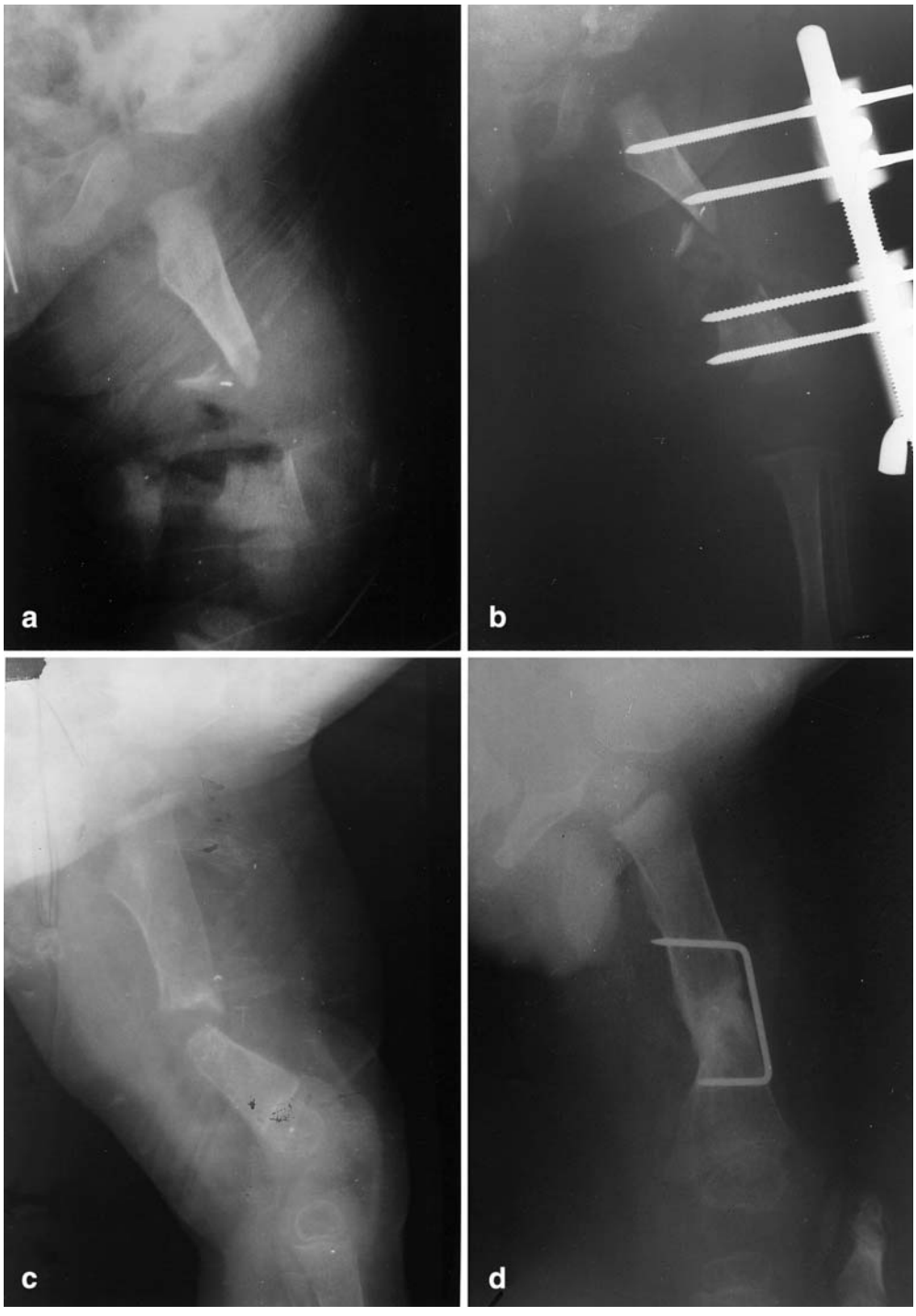

Fig. 4 **A** Defective fracture of the left femur in a 8-month-old boy due to high velocity gunshot injury. **B** This patient was treated with debridement, reduction, and external fixator. **C** Radiograph shows nonunion 4 months after injury. **D** Four months after injury, fibular autograft was carried out; however, union still did not occur, and further surgery was necessary. Compression-distraction with an Ilizarov circular external fixator was applied, but this procedure was not effective. At age 3 years, decortication, minimal osteosynthesis with staples, and plaster were applied, and union was achieved

duction and internal fixation in our clinic, and 6 in other clinics. Five of these patients had infections, 1 in the soft tissue. Three of the six patients with open fractures were treated in our clinic and 2 in other centers, while the last received primitive treatment. Five of the open fractures involved the tibia and 1, the femur, and the initial treatment included debridement and external fixation. Patients with nonunion following pathologic fracture were treated conservatively with plaster.

Fourteen patients had infections; 13 had bacterial osteomyelitis, and 1 had soft-tissue infection. Seven of these infections were in patients suffering pathologic fractures associated with osteomyelitis. While 3 of the other patients had developed infection subsequent to an open fracture, 4 occurred after open reduction and internal fixation. *Staph. aureus* was produced in a total of 10 patients, alone in 8 and associated with *E. coli* and *Pseudomonas* in two. *Pseudomonas* was produced alone in 2 patients. In the remaining 2 patients, no bacteria were produced, and infection was diagnosed according to clinical and laboratory findings.

According to Weber and Cech's pseudarthrosis classification system, 10 of the patients were atrophic, 9 were

hypertrophic, and 7 were oligotrophic. Eight of the 10 patients with atrophic-type pseudarthrosis also had infections.

Nineteen of 26 nonunion patients received initial treatment in our clinic. Seven of these patients underwent decortication with external fixator, 3 underwent decortication with external fixator and autograft, 3 underwent circular fixator with external bone transport, 2 underwent decortication with osteosynthesis and autograft and plates, and 3 underwent decortication with autograft and plaster. Three of the patients' fractures did not knit, and these patients underwent reoperation. Our 1-year-old patient, who had received treatment with fibula autograft and plaster because of nonunion, underwent compression-distraction with an Ilizarov circular external fixator, but this procedure was not effective. At age 3, this patient underwent decortication with staples and minimal osteosynthesis with plaster, and union was achieved (Fig. 4). In the patient with defective nonunion in the radius and ulna, the implants were removed because of loosening, and iliac bone grafts were applied. In spite of continued nonunion at the carpal level, this patient performs daily life activities with the aid of a splint (Fig. 3). The third patient who required reoperation and who had nonunion in the distal diaphysis of the tibia, underwent 2-cm fibular osteotomy and posteromedial graft, and union was achieved.

Discussion

Nonunion is seldom seen in the diaphysis of bones whose physeal lines have not closed and is especially rare in children 10 years of age and younger. In a series of 85 patients, Grimard et al. [4] reported 10 with delayed union and 7 with nonunion, all in patients over 6 years of age. In the same study, they stressed that one of the most important factors in nonunion was age, and that from 12 years on, delayed union and nonunion were seen at rates close to those of adults. In a similar study, Kreder and Armstrong [5] found that age was the second most important factor in the healing of open fractures, the first being the Gustilo classification. They stated that delayed union and nonunion did not occur before the age of 6, and that there was a statistically significant difference in union rates before and after this age. Lewallen and Peterson [7] indicated that 27 out of 30 children with long bone nonunion were between the ages of 12 and 16. Almost all authors who discuss the effect of age on nonunion agree that it begins to be encountered at age 6, and that there is an increase in frequency after age 10. At variance with the literature, in our study there were two cases of nonunion in patients under 6, and the frequency increased from the age of 6 on. Our observations suggest that 6 rather than 10 is the cutoff age. While 10 years is a valuable cutoff in terms of comparison with adult fractures, we think it is less significant than other authors believe.

Lewallen and Peterson [7] determined that nonunion is less common in the upper than in the lower extremity. These authors also made the interesting observation that most such cases occur in fractures of both forearm bones, and that there is almost always union in one of the two bones. The cases in our study were in accordance with the literature insofar as only 4 (15%) were in the upper extremity, all of these in the forearm. In contrast with the literature, however, one patient had atrophic nonunion in both the ulna and the radius; this patient's fractures occurred in association with osteomyelitis. The initial treatment was primitive, and we learned that several procedures had been performed at various times in this patient's history.

In all age groups, one factor affecting union is whether the fracture is open or closed, but this factor is more significant in childhood. Especially after epiphyseal closure, epiphyseal nonunion occurs more readily for mechanical reasons. At the same time, nonunion virtually never occurs in children with closed fractures treated with the correct conservative methods [7]. In children with open fractures, however, nonunion may occur, albeit not at the same rate as in adults, especially in pediatric open fractures with segmentary defect and excessive soft-tissue loss, even if the fracture is treated correctly. In the literature, this is reported to be the primary cause of nonunion [2, 3, 4, 7]. Lewallen and Peterson [7] indicated that soft-tissue loss was a factor contributing to nonunion in 17 patients in their 30-patient series. In studies on open fractures in children, nonunion rates of 0%–8% are reported [4, 5, 8]. The cause of nonunion in 6 of our patients was open fracture.

Open reduction and internal fixation negatively affect bone union in children, especially when the fixation material is insufficient and inappropriate. Lewallen and Peterson [7] stated that insufficient and inappropriate fixation material was used in five out of six patients undergoing open reduction and internal fixation. Eleven of our patients who initially had closed fractures underwent open reduction and internal fixation. These patients each had one or more unfavorable conditions, such as an indication error, insufficient fixation, or infection. Indications for surgical therapy should be well assessed, and use should be limited in order to prevent nonunion in pediatric closed long bone fractures, and if fixation is to be performed, it should be done with appropriate materials in accordance with osteosynthesis principles.

Although there are no published clinical studies on the effects of peripheral nerve damage on union, Aro [1] demonstrated that sciatic denervation accompanying tibial fracture in rats had a negative effect on union. In our patient who suffered a segmental defect fracture at 8 months of age, sciatic nerve damage was also present, which may have been a factor in the occurrence of therapy-resistant nonunion.

Pathologic fractures associated with hematogenous osteomyelitis are not uncommon. Because of unfavorable local biological factors in such fractures, healing is slower than in normal fractures, and often incomplete. An interesting finding in this study was the fact that 8 of the 10 patients with atrophic nonunion had infections.

In selecting fixation material, we tended to prefer external fixators in order to avoid performing a second oper-

ation for removal, and to reduce the risk of exacerbation in patients with infection. Autografts were used in 9 patients with atrophic and oligotrophic nonunion. The therapeutic principles for long bone nonunion in children are the same as in adults. It should be kept in mind, however, that nonunion in children may be resistant to therapy, as it was in 3 of our patients.

Various authors' claims that long bone nonunion in children is extremely unusual and always the result of therapeutic error are, in our opinion, exaggerated. We have observed that it may occur despite correct treatment in open fractures, especially those with accompanying loss of bone and soft tissue and those associated with infection. The effect of peripheral nerve damage on union needs to be investigated. Our experience suggests that the rate of nonunion increases from the age of 6 and not the age of 10, as reported by many authors.

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