REVIEW ARTICLE

Open tibial fractures. Are children small adults?

Gougoulias NE, Khanna A, Maffulin N

University Hospital of North Staffordshire, Stoke on Trent, UK

Abstract

Open tibial fractures in adults have been extensively studied. In children, however, only a small number of case series provide data on management and outcome of these injuries. It is not clear whether open tibial fractures in children 'behave' in a similar fashion to those in adults, and clear guidelines regarding their management do not exist. Primary wound closure after irrigation does not increase infection rates in low grade open tibial fractures. Cast is an effective method for fracture stabilization in stable fractures. External fixation is usually used in patients with significant soft tissue injury, and elastic intramedullary nailing is an alternative. Age over 10 years and open fracture grade III appear to be significant prognostic factors. Complication rates are not unremarkable and long-term studies are required to investigate their consequences. Children over 10 years should probably be managed as adults. Further research is needed to evaluate the effectiveness of different fracture management methods. Hippokratia 2009; 13 (3): 147-153

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Corresponding author: Gougoulias Nikolaos, 23 Ashenden Road, Guildford, Surrey, GU2 7UU, UK. e-mail: gougnik@yahoo.com

Open fractures of the tibia in adults are challenging injuries. Frequently they are associated with multiple injuries[1] and management requires general assessment, resuscitation of the patient if required and early fracture stabilization, preferably within 6 hours, with appropriate broad spectrum antibiotic coverage[2,3]. Vascular compromise may require revascularization procedures or amputation in limbs with prolonged ischemia, extensive soft tissue injury, or in patients with significant co-morbidities indicating low biologic potential to attempt reconstruction[2-7]. Tibial nerve transection and insensate foot is also a relative indication for primary amputation[2-8]. Fracture stabilization methods vary depending on fracture severity and the presence of concomitant injuries. External fixation is the method of choice for grade IIIC fractures (vascular injury requiring repair) according to the Gustillo-Anderson classification, or for unstable patients requiring a quick and urgent stabilization. Intramedullary nailing is most commonly used for grade I and II open fractures. Internal fixation with less invasive methods and the use of locking plates is gaining in popularity. Recently the use of locked intramedullary nailing has been spread for III-A and III-B in certain centers. Alternatively external fixation can be used[2-4]. The presence of contamination requires debridement in the operative room and soft tissue and bone loss are common in high energy injuries. It is common practice that open wounds are not primarily closed. Soft tissue management includes delayed closure, secondary healing, vacuum assisted closure, or coverage with split thickness skin grafts, local fasciocutaneous flaps, local rotational muscle flaps (usually medial gastrocnemius or soleus) or free tissue transfer (e.g. latissimus dorsi muscle flap) which requires microsurgical skills[2-5].

Recovery is not always uncomplicated. Infection and nonunion (septic or aseptic) are common consequences of open tibia fractures in adults and complex reconstructive procedures, including the need for bone grafting and/or bone transport (distraction osteogenesis) are sometimes required. This lengthens the recovery time with a negative psychosocial impact for the patient[2-8].

Although open tibia fractures in adults have been thoroughly investigated in the literature, these injuries in children are less well studied and clear guidelines do not exist[9,10]. Open fractures of the tibia represent approximately 5% of all tibial fractures in children[11,12] and the literature on their management and outcome consists of a relatively small number of retrospective case series, with only short term follow-up. Although most closed tibial fractures in children can be managed non-operatively[9,10] it is not clear whether open tibial fractures in children should be approached along the same principles applied to the adult population. Should wounds be left open after debridement and the fracture stabilized by operative intervention, as is common in adults? Is a better healing potential in children sufficient to justify a more conservative approach? Is selective primary wound closure appropriate to avoid repeated surgical interventions? The present study reviewed the literature reporting on outcomes of open tibial fractures in children[11-31] and compared the results to those reported in adults[3].

Published studies

Outcomes of open tibial fractures in children

Tolo[13] presented in 1983 one of the early reports of the use of external fixation for fractures in children, including 13 tibial fractures. Leg length discrepancies and

potential overgrowth in some cases raised an issue. Six of the 13 children had purulent drainage at some time during their treatment, although no chronic infections resulted. The use of external fixation was recommended in children with open fractures with skin loss or burns, in children with head injury and resultant increased motor tone, and in polytrauma patients, to facilitate patient care and transport for diagnostic and therapeutic procedures.

Hull et al[14] reviewed diaphyseal fractures of the femur and tibia managed with external fixation between 1987 and 1994 in 48 children. The indications for external fixation included open fractures, multiple injuries, failed conservative management, and unstable fracture configurations. All fractures healed without further surgical intervention, and the incidence of serious complications was low, although pin track sepsis was common.

Buckley et al[15] reported on 42 open tibial fractures in children with a mean age of 9.8 years. Grade I fractures according to the Gustillo classification[6,7] were treated with cast in 10 of 11 patients. External fixation was used in 20 fractures. The time to union was related to the severity of the soft-tissue injury, the pattern of the fracture, the amount of segmental bone loss, the occurrence of infection, and the use of external fixation. No relation between age and outcome was found. The same group of authors later reported on 20 grade III open tibial fractures in children with a mean age of 9 years[16]. The time to fracture union (mean 29 weeks) was related to the severity of soft tissue injury, fracture configuration, segmental bone loss, and infection. Fifteen fractures were initially treated with external fixation, three with casts, one with internal fixation, and one with a combination of external fixation and limited internal fixation. Free muscle flaps were used for soft-tissue coverage in six patients (30%), and a local muscle flap in one patient.

Irwin et al[11] reviewed 58 children (mean age 8 years) with open tibial fractures, out of a total of more than 1400 tibial fractures treated in their centre over a 20 year period (1971-1992). Primary wound closure was performed in 37/58 (64%) of fractures, and closed reduction followed by cast immobilization was used in 48/58 (83%). Ten fractures were classified as Gustillo type III, two requiring amputation. Higher open fracture grade was associated with longer time to union and more complications. No infection occurred in grade I open injuries. Primary wound closure was associated with a 3/37 (8%) infection rate, compared to 3/21 (14%) for wounds initially left open. The authors recommended primary wound closure after debridement and cast immobilization for grade I open tibial fractures. For grade II and III injuries, they suggested more radical debridement, use of external fixation, and early wound coverage by skin graft or flaps if necessary.

Hope and Cole[17] reviewed 92 open tibia fractures in children (mean age 9.3 years) treated between 1981 and 1989. The condition of the soft tissues guided treatment. Cast immobilization was chosen in 65/92 (71%) patients, and primary wound closure in 50/92 (55%). There was an incidence of deep infection of 4/51 (8%) in wounds closed primarily compared to 6/41 (15%) of those left open, suggesting that selective primary closure did not increase the infection rate. The use of external fixation in 26 (more severe) fractures was associated with 9 delayed unions (35%) and 5 nonunions (19%). Children treated with cast for less severe fractures had a delayed union rate of 5/65 (8%) and nonunion rate of 2/65 (3%), respectively. Their incidence of early complications was similar to other series. A review between the ages 1.5 and 9.8 years showed a high incidence of continuing morbidity, including pain at the healed fracture site in 37/74 children (50%), restriction of sporting activity in 17/74 (23%), joint stiffness in 17/74 (23%), cosmetic defects in 17/74 (23%) and minor leg length discrepancies in 41/64 (64%). A high incidence of early and late complications was more frequent in children with Gustilo type III injuries. The Gustilo classification was useful to predict the outcome and plan treatment. Age was also associated with outcome, although no statistical analysis was performed. Delayed union or nonunion occurred in 39% of adolescents between 13 and 16 years.

Cullen et al[18] reviewing 83 children treated from 1983 to 1993, applied the 'pins and plaster' technique or plaster alone in the vast majority of their patients, closing the wound primarily over a penrose drain after debridement and irrigation. Their time to union was 15 weeks. Only one patient had a non-union, and 18 (22%) had delayed union. The authors advocated the pins and plaster technique instead of external fixation.

Levy et al[19] evaluated the social impact of open tibia fractures in 40 children with a mean age of 10 years. The children surveyed missed an average of 4.1 months of school, and 13 children (33%) had to repeat a year. Ten children (25%) complained of nightmares involving the events of the accident. Chronic pain despite solid union was found in 12 patients (30%). Sixteen children (40%), 7 with a grade III open fracture, reported a limp.

Grimard et al[20] studied 90 open fractures of the tibia in children treated between 1984 and 1995. Cast without any form of fixation was used in 40 fractures (45%), and primary wound closure was performed in 17 (19%). Multiple regression analysis showed that the age of the patient and the grade of the fracture were significantly associated with union time. Open fractures of the tibia in children older than 12 years of age had a high risk of developing delayed or nonunion when compared with the same injuries in children younger than 6 years of age.

Age was the most important factor determining the outcome of open tibial fractures in children according to **Blasier and Barnes**[21], who reviewed the medical records of 31 children treated between 1982 and 1988. They divided their patients into two groups: children younger than 12 years healed faster, were more resistant to infection, and had overall fewer complications, compared to older children. More than half of the younger children were treated in a cast. Both groups were equivalent in terms of fracture grading according to Gustillo and An-

derson,[6,7] but children older than 12 may have been subject to higher energy injuries.

Kreder and Armstrong[22] studied 56 fractures in 55 children, with a mean age of 10 years treated between 1975 and 1990. All wounds were left primarily open. Despite the high prevalence of severe open fractures (26/56 were classified as grade III), 25 were treated in plaster (45%). External fixation was the second most common choice of fixation (23/56 fractures). Mortality rate was high (4/55 patients, 7.3%), deep infection rate was 3/56 (5.4%), and mean time to union was 5 months. Four amputations were required in 8 limbs with vascular injury. For healed fractures classified as IIIb and IIIc, the mean time to union was 10.8 and 10.4 months respectively. Grade I fractures healed at 4 months, grade II at 3.8 and grade IIIa at 5.9 months. Nonunion occurred in 4 of 48 fractures (8.3%). The most significant factor affecting time to union, after controlling the Gustillo grade of the injury, was the age of the patient.

Robertson et al[23] reviewed the medical records of patients younger than 17 years treated for a tibial fracture from 1987 to1992. Thirty-two patients with a mean age of 10.2 years had an open fracture. The open wound was left primarily open. A cast was applied in 16 patients; external fixation was used in 9, elastic nails in 3, and internal fixation in two patients. A primary amputation was required in two patients (2 of 3 IIIc fractures). No nonunions occurred, but 7 fractures (22%) healed with angular malunion.

Bartlett et al[24] performed a combined retrospective and prospective review of their treatment protocol for 23 grade II and III open tibial fractures in children aged 3.5 to 14.5 over a ten-year period (1984 to 1993). Their protocol consisted of debridement of soft tissues and stabilization with external fixation. All fractures healed. There were no deep infections, growth arrests, or malunions. Bone graft was not required, and the authors concluded that children's periosteum has osteogenic potential to compensate for in cases with bone loss.

Jones and Duncan[12] studied 83 children younger than 13 years of age (mean 7.2 years) treated between 1980 and 1988 for an open tibial fracture. They represented 6.5% of a total of 1276 tibial fractures in children treated during the same period in their centre. They were mainly treated with cast immobilization (65/83 fractures, 78%). Only one non-union was recorded, and union occurred at a mean of 12.9 weeks. External fixation was associated with prolonged time to union, a common finding in other studies as well[10,14,19,22] and may reflect the higher grade of severity of these fractures. No deep infections and no amputations were recorded. It seems that in this younger age group fracture healing is more predictable and complication rate is low.

Similarly, **Song** et al[25] found that all nonunions in their series occurred in children older than 11 years who had grade III injuries. Patients younger than 11 years without internal fixation had a significantly shorter ($p<0.05$) time to healing. In their series, an average union time of 29 weeks was recorded for grade III fractures (all treated by internal or external fixation). Grade II fractures healed at 19.5, and grade I fractures at 13.5 weeks. Fracture stabilization method in grade I fractures (cast or external fixation) did not influence time to healing (13.7 vs. 13 weeks respectively). Fractures in children younger than 11 years had a mean time to union of 14.1 weeks compared to 21 weeks for children older than 11 years. It was not possible to demonstrate an effect of the fracture fixation method on time to union.

Qidwai[26] reported the use of intramedullary Kirschner wires, introduced antegrade from proximal (level of tibial tuberosity), for tibial fracture stabilization in children. He treated 84 tibial fractures, 30 of which were open. No delayed unions occurred, and the fractures healed at 9.5 weeks. One open IIIb fracture was complicated by a septic non-union.

Myers et al[27] evaluated the use of external fixation in 30 high energy tibial fractures (19 open, 11 closed) in children with a mean age of 11.9 years, followed for 15 months. The mean time to union was 4.8 moths, whereas the fixator was kept in situ for 3.2 months. A high incidence of complications was presented: 4/30 (13%) had delayed union, 2/30 (6.7%) had nonunion, 3/30 (10%) had malunion, 3/30 (10%) had leg length discrepancy, 8/30 (27%) had pin track infection, 3/30 (10%) had wound infection and 2/30 (6.7%) developed osteomyelitis. Time to union differed significantly between those aged 11 years or younger and those aged 12 years or older. Union time also differed significantly between patients with closed or grade I open fractures and those with grade II or III open fractures (3.9 and 5.7 months, respectively; $p = 0.035$). Leg length discrepancy rate differed significantly between children aged 11 years or younger and those aged 12 years or older (3/13 and 0/18, respectively; $p = 0.05$).

Sristava et al[28] reported on elastic intramedullary nailing in 16 open tibial fractures treated from 1997 to 2005 in patients with a mean age of 10.2 years. Nine fractures were classified as type III (IIIa: 5, IIIb:4). The average union time was 20.2 weeks and 5 delayed unions (31%) and 2 non-unions (13%) were recorded. Both occurred in IIIb type fractures. Other complications were one infection (6%), and 2 malunions (13%). Minimally contaminated wounds were treated by primary closure after debridement and irrigation. These results, although obtained from a small case series, raise concerns regarding the use of flexible intramedullary nailing for the treatment of open fractures in children.

Vallamshetla et al[29] reviewed 56 paediatric tibial fractures that were treated with elastic intramedullary nailing. Thirty-five were caused by high energy trauma and 13 were open. Mean age on the day of surgery was 12 years and the children were followed for 2 months after nail removal. There were no nonunions, the time to union was 10 weeks and all patients were reported to have an excellent outcome, despite the presence of angular deformities (2 patients), leg length discrepancies (shortening >1.5cm in 2 patients), delayed union in one patient and infections

in3 patients. In two patients the fixation was revised to a plate (a week after primary elastic nailing) because of failure. Routine nail removal failed in 2 patients.

Kubiak et al[30] demonstrated better outcome of elastic nailing over external fixation. They retrospectively reviewed a series of 31 paediatric tibial fractures (18 closed, 13 open). The grade of the open fractures was not mentioned. Fifteen patients had 15 fractures (7 closed, 8 open, mean age 10.3 years) and were managed with external fixation and followed for 3.5 years, whereas 16 (11 closed, 5 open, mean age 11 years) were managed with elastic intramedullary nailing and followed for 2.9 years. In the elastic nailing group time to union was significantly shorter (7 weeks vs. 18 weeks for the external fixation group, $p<0.001$). Functional outcome evaluating pain, happiness, sports, global function was also significantly better ($p<0.001$) in the elastic nailing group. Pin tract infections occurred in patients treated with external fixation, whereas an anterior compartment syndrome was a serious complication in one patient treated with an elastic nail.

Gordon et al[31] reviewed tibial fractures of 60 children's (31 closed and 29 open, patients' mean age 11.7 years) treated with flexible intramedullary fixation. Fifty patients with 51 fractures were followed until union. Although 45 fractures united at a mean of 8 weeks, 3 went on to delayed union (longer than 18 weeks) and 2 had a nonunion requiring reoperation. The latter 5 fractures occurred in patients of a mean age of 14.1 years and united at a mean of 41 weeks. Other complications included one malunion requiring correction, one deep infection (osteomyelitis) and one nail migration. The authors highlighted the remarkable delayed union rate in older children.

Table 1 gives an outline of the main conclusion(s) ob-

Table 1: Main conclusion(s) of studies reporting on open tibial fractures in children.

Study	Main message
Irwin et al.[11]	Primary wound closure safe in low grade open fractures
Jones & Duncan[12]	Severity of fracture associated with non-union rate
Tolo[13]	ExFix: Certain indications, LLD can occur
Hull et al.[14]	ExFix: Certain indications, pin tract infections common
Buckley et al.[15,16]	Time to union influenced by severity of fracture and soft tissue injury
Hope & Cole[17]	Worse results with higher grade open fractures Significant morbidity in the long term (pain, cosmetic defects, LLD) and restriction to sporting activities
Cullen et al.[18]	Primary wound closure safe in low grade open fractures Pins and plaster instead of ExFix
Levy et al.[19]	Significant social impact (33% repeated year at school, pain, nightmares)
Grimard et al.[20]	Age and grade of fracture significantly associated with union time
Blasier & Barnes[21]	Age above 12 years associated with more complications
Kreder & Armstrong[22]	Age and grade of fracture significantly associated with union time
Robertson et al.[23]	Severe complications frequent in high grade fractures
Bartlett et al.[24]	Good results with soft tissue debridement and ExFix
Song et al.[25]	Age and grade of fracture influence time to union and outcome
Qidwai[26]	Intramedullary Kirschner wires are an option
Myers et al.[27]	Age and grade of fracture influence time to union and outcome
Shristava et al.[28]	Evaluation of ESIN in open tibial fractures in children
Vallamshettla et al.[29]	ESIN is an effective method for tibial fractures in children
Kubiak et al.[30]	ESIN is superior to ExFix
Gordon et al.[31]	Higher delayed union / nonunion rate in older children

(ExFix: External fixation; LLD: Leg length discrepancy; ESIN: Elastic intramedullary nailing)

tained by the studies reporting on open tibial fractures in children.

Outcomes of open tibial fractures in adults

In a systematic review, Giannoudis et al.[3] analysed 30 studies reporting management and outcomes of open diaphyseal tibial fractures in adults. Methods used for fracture stabilisation were external fixation, reamed intramedullary nailing, unreamed intramedullary nailing, internal fixation with plates. In 53% the tibial fracture was not an islated injury.

External fixation was used in 536 fractures of which 82% were grade-III open injuries. In all fractures soft-tissue coverage was delayed for more than 72 hours. Union occurred at a mean of 37 weeks and union rate was high (94%). The incidence of delayed union, (union later than six months), was 24% as in a total of 392 fractures. Additional procedures to achieve union (at least one per fracture), was required in 69% of 536 fractures treated with external fixation. The malunion rate using external fixation was up to 20% in 458 fractures, whereas deep infection occurred in 16% and pin track infections in 32% of fractures. **Unreamed intramedullary nailing** was used in 666 fractures (53% were grade III).The union rate with unreamed intramedullary nailing was 97%, whereas 22% of fractures went into delayed union. Complications included malunions (10%) and infections (7%), whereas 33% of the fractures required additional procedures. A meta-analysis of results showed no statistically significant difference between external fixation and unreamed intramedullary nailing with respect to union, delayed union, and deep infection. **Reamed intramedullary nails** were used in 187 fractures of which 43% were grade-III open injuries. Soft-tissue coverage was reported for 80 fractures and was undertaken within 24 hours in 2.5% of, between 24 and 72 hours in 37.5% and in 60% later than 72 hours. Union rate was 97%, while deep infection was 6.4%. Malunion rate was 6% and 32% of fractures required at least one further procedure. The rate of failure of the implant was low (3%), in comparison with unreamed nailing (12%). They did not find statistically significant difference between reamed and unreamed nailing for open tibial fractures with regard to the time to union, the rate of union and infection. Delayed reamed nailing after initial external fixation in 91 open fractures (51 were grade III), results in union in 92% of fractures, at a mean time of 38.5 weeks. Deep infection rate was 17%, delayed union occurred in 14%, malunion in 11%, whereas 23% of fractures required at least one additional procedure. The use of **plates and screws** was uncommon in open tibial fractures. Although all 26 fractures united (29% were grade III), with only one malunion (4%), delayed union and deep infection rates were high (38% and 35% respectively) and 69% of fractures required additional procedures. Cast immobilisation for open tibia fractures in adults was not reported in any of the studies. Early soft tissue coverage in grade III open fractures reduced the risk of wound complications, as well as deep infection and malunion. The incidence of compartment syndrome in 198 open fractures was 9% and 83% of the fractures which developed a compartment syndrome were grade III. Amputation is a frequent (50-73%) consequence in grade IIIC open fractures[2,3,8].

In summary, irrespective of the fixation method used for open tibial fractures in adults, union rate exceeded 90% and time to union was in the range of 9 to 10 months. The proportion of grade III open fractures varied between different fixation methods (higher when external fixation was used). Additional procedures were more common when external fixation or plate and screws were used. Malunion was more common with external fixation and infection rate was higher when plate and screws were used and lower with intramedullary nailing (reamed or unreamed)[3].

Discussion and interpretation of results

Direct comparison of outcomes between children and adults is not possible, because of the different techniques used and the heterogeneity in the methodologies of the individual studies. Furthermore, the term 'open tibial fractures' does not represent a homogenous condition, and variation in open fracture grade, patient characteristics, concomitant injuries and management methods, can influence results. Also, given the lack of uniformity in the presentation of methods and results in the individual studies, any comparisons are mostly tentative. We also need to emphasise, that when treating the immature growing skeleton, the dimension of time becomes very important. Injury consequences might only be evident after longer follow up.

Most studies on open tibial fractures in children report on fractures treated before 2000. Therefore, the techniques described may not reflect the current management for open fractures in children. Summarizing data, most children sustaining an open tibia fracture were boys [range 55% (32/58) to 88% (14/16)][11,28]. The mechanism of injury was usually a car hitting a pedestrian or a bicycle, the percentage ranging from 64% (36/55) to 92% (76/83) of accidents in different studies[12,22]. The tibial fracture was frequently [in 19% (16/83) to 58% (48/83) of the children] accompanied by other injuries[10,12]. This is comparable to a 53% incidence of other injuries documented in adults[3]. Other long bone fractures, blunt chest trauma and head injuries often co-existed. Mortality rates of 0 to 7.3% (4/55)[22] have been reported.

There was a trend towards primary closure of open wounds in selected injuries, but there was no consensus in wound management between different studies, and no defined protocols were presented. The reported primary wound closure rates range from 0 to 69% (57/83)[18,21] Skin grafts or flaps were required in up to 36% (20/56)[22]. Variation exists in the severity of fractures in different studies. Type III open fractures accounted for 17% (10/58) to 74% (17/23) in different case series[11,24]. In adults[3] a higher proportion of fractures were grade III (29% of fractures treated with plate and screws, 43% of those

treated with reamed nailing, 53% when unreamed nailing was used and 82% of fractures treated with external fixation. Cast immobilization without any form of fixation was used in 0 to 83% (48/58) of the fractures in children[11,23]. The authors usually mentioned that low grade open fractures were managed by cast, but occasionally the same applied to higher grade open fractures (type II and III). External fixation was used for more severe fractures with great variability among different studies (0 to 100% of fractures)[24,26]. An alternative to external fixation was the 'pins and plaster' technique[18]. Other studies[23,25] recommend early (at 7-8 weeks) removal of the external fixator and application of a cast to avoid complications associated with the use of external fixation. Skeletal traction was used in only two patients with an ipsilateral femoral fracture. Intramedullary fixation techniques for open tibial fractures in children have been used in two recent studies[26,28]. The use of intramedullary nailing is far more frequent in adults[3].

Not only treatment strategies, but also outcomes show a wide range of variation. Time to fracture union in children ranged between a mean of 9.2 and 29 weeks. This is probably associated with the different prevalence of severe open fractures and the variation in childrens' age among different studies. Time to union in adults was more prolonged[3]. This may reflect the greater healing potential in children[10], but also the lower incidence of grade III open fractures. Nonunion rates ranged from 0[23,24] to 13% (2/16)[22], delayed union ranged from 0[25,26] to 35% (11/31)[21], and malunion complicated 0[20] to 22% (7/32)[23] of fractures in different studies. These figures are similar to outcomes reported in adults[2,3]. Deep infection rate was below 11% (maximum 10/92)[17] in all studies, which is lower compared to a 7-35% rate reported in adults[2,3]. Compartment syndrome complicated 0[20] to 8.5% (7/83)[12] of fractures and neurovascular complications occurred in 0[21,26] to 14% (8/56)[22]. Amputation rates in IIIC open tibial fractures in children range between 0[12,15-17,25] and 67% (2/3)[23]. This is to be compared to the 50-73% amputation rate in adults with IIIC type open fractures reported in the literature[2,3,8]. Leg length discrepancy was recorded in 0[12,20,23,25,26] to 26% (6/23)[24] of patients, however most studies followed their patients only for short time after the fractures had healed, or were based on reviewing the medical records. The mean follow-up usually ranged between 6 and 33 months, and in the only one study[17] which followed their patients for 1.5-9.8 years, problems were present in the long term, indicating the necessity for long-term follow-up when evaluating the growing skeleton. The heterogeneity of fracture types included in the individual studies reporting on the management of open tibial fractures in children, explains the variation and the wide range in the values of the several parameters (eg. fracture stabilization and soft tissue closure techniques, time to union, complications).

The age of the children with an open tibial fractures influenced the outcome in some studies[17,20-23,25,31]. An age below 10 years was generally associated with more rapid fracture union and less complications. A higher fracture grade according to the Gustillo classification was associated with worse results[11,12,15,17,20,22,23,25].

Only one study[30] used a validated functional outcome measure. Presentation of results was based on empiric assessment by non-independent examiners. In most studies, patients were not recruited, and assessment was based on their medical records. These are of course subject to bias and these results should be used with extreme caution to evaluate efficacy of treatments. Subjective interpretation of variables can lead to inaccurate conclusions.

Given the methodological flaws present in all studies, the existing literature shows that the results of treatment of open tibial fractures in older children are in some aspects similar to those reported in adults. There is a trend towards better results (shorter times to union and fewer complications) for children younger than 10-12 years and low grade open fractures. Wounds in grade I fractures are probably caused by inside – out trauma representing a favourable scenario[10], and can be safely managed with primary closure after irrigation. If the fracture is reducible and stable, plaster cast immobilization is a reliable method of treatment. Grade II or III open fractures are associated with a higher complication rate and longer union times. These injuries should be treated with delayed wound closure, and may require a skin graft or a flap. Surgical fracture stabilization is usually required. Grade III fractures are associated with longer healing time, whereas complications and amputation rates are comparable to those in adults. The periosteum in children has a significant osteogenic activity[9,10] It is likely however, that more severe open fractures in children older than 10 years, associated with soft tissue disruption have a decreased healing potential. This applies also to closed high energy tibial fractures[27]. It should always be kept in mind that most (60-92% in the presented studies) injuries were caused by a motor-vehicle hitting a pedestrian or a bicycle (high energy). Although there are no data to support this, it is more likely that children older than 10 years (more independent from their parents compared to younger ones), are more likely to sustain a high energy injury.

New fracture fixation techniques, such as flexible intramedullary nailing, have recently gained in popularity for the treatment of closed and open fractures. Recent studies[28-31] report on elastic intramedullary nailing, some including both closed and open fractures[28-31]. Results have not been evaluated adequately, and although promising, require careful interpretation. Although some of the authors concluded that 'flexible intramedullary nailing is an easy and effective method' and 'excellent outcome was achieved in all patients[29], the complications rate and the need of reoperation for fixation failure they reported, cause scepticism. Superiority of nailing over external fixation shown in a retrospective study[31] should be interpretated with caution, as the grade of open fractures was not reported. Since it was not a randomised prospective study, it is likely that more severe open fractures and se-

vere high energy closed fractures were treated with external fixation. Randomisation of children with an open tibial fracture, between different management methods for research purposes carries certain difficulties. Effectiveness of different management protocols should, at least, be evaluated by prospective studies in groups matched for age and severity of injury. The social impact of these injuries and their relevance to the quality of children's life should not be underestimated[17,19]. The use of flexible intramedullary nailing in open tibial fractures has yet to be evaluated. Further research is needed to improve our understanding of the interaction between age, severity of injury, concomitant injuries, type of fracture fixation and outcome.

Conclusions

Low grade open fractures in children younger than 10 years can be managed with cast immobilization and primary wound closure after irrigation. High grade open fractures and fractures in children older than 10 years should be approached as in adults. Expected time to union of an open tibial fracture may be shorter in children, compared to adults, however complication rates are comparable, and the long term outcomes in children are not known. Children are not small adults, not because of favourable outcome after a fracture, but because of the possible long term effects of complications and associated morbidity.

References

1. Court-Brown CM, Rimmer S, Prakash U, McQueen MM. The epidemiology of open long bone fractures. Injury. 1998; 29: 529–534.
2. Zalavras CG, Marcus RE, Levin LS, Patzakis MJ. Management of open fractures and subsequent complications. J Bone Joint Surg Am. 2007; 89: 884-895.
3. Giannoudis PV, Papakostidis C, Roberts C. A review of the management of open fractures of the tibia and femur. J Bone Joint Surg Br. 2006; 88: 281-289.
4. Gopal S, Majumder S, Batchelor AG, Knight SL, De Boer P, Smith RM. Fix and flap: the radical orthopaedic and plastic treatment of severe open fractures of the tibia. J Bone Joint Surg Br. 2000; 82: 959–966.
5. Naique SB, Pearse M, Nanchahal J. Management of severe open tibial fractures: the need for combined orthopaedic and plastic surgical treatment in specialist centres. J Bone Joint Surg Br. 2006; 88: 351-357.
6. Gustilo RB, Anderson JT. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones. J Bone Joint Surg Am. 1976; 58: 453–458.
7. Gustilo RB, Mendoza RM, Williams DN. Problems in the management of type III (severe) open fractures: a new classification of type III open fractures. J Trauma. 1984; 24: 742–746.
8. Hoogendoorn JM, van der Werken C. Grade III open tibial fractures Functional outcome and quality of life in amputees versus patients with successful reconstruction. Injury. 2001; 32: 329-334.
9. Mashru RP, Herman MJ, Pizzutillo PD. Tibial shaft fractures in children and adolescents. J Am Acad Orthop Surg. 2005; 13: 345-352.
10. Rodrigez-Merchan C. Pediatric skeletal trauma. Clin Orthop Rel Res. 2005; 432: 8-13.
11. Irwin A, Gibson P, Ashcroft P. Open fractures of the tibia in children. Injury. 1995; 26: 21-24.
12. Jones BG, Duncan RD. Open tibial fractures in children under 13 years of age - 10 years experience. Injury. 2003; 34: 776-780
13. Tolo VT. External skeletal fixation in children's fractures. J Pediatr Orthop. 1983; 3: 435-442.
14. Hull JB, Sanderson PL, Rickman M, Bell MJ, Saleh M. External fixation of children's fractures: use of the Orthofix Dynamic Axial Fixator. J Pediatr Orthop B. 1997; 6: 203-206.
15. Buckley SL, Smith G, Sponseller PD, Thompson JD, Griffen PP. Open fractures of the tibia in children. J Bone Joint Surg Am. 1990; 72: 1462–1469.
16. Buckley SL, Smith G, Sponseller PD, Thompson JD, Griffen PP. Severe (type III) open fractures of the tibia in children. J Pediatr Orthop. 1996; 16: 627–634.
17. Hope PG, Cole WG. Open fractures of the tibia in children. J Bone Joint Surg Br. 1992; 74: 546–553.
18. Cullen MC, Roy DR, Crawford AH, Assenmacher J, Levy MS, Wen D. Open fracture of the tibia in children. J Bone Joint Surg Am. 1996; 78: 1039-1047.
19. Levy AS, Wetzler M, Lewars M, Bromberg J, Spoo J, Whitelaw GP. The orthopedic and social outcome of open tibia fractures in children. Orthopedics. 1997; 20: 593-598.
20. Grimard G, Naudie D, Laberge LC, Hamdy RC. Open fractures of the tibia in children. Clin Orthop Relat Res. 1996; 332: 62-70.
21. Blasier DR, Barnes LC. Age as a prognostic factor in open tibial fractures in children. Clin Orthop Rel Res. 1996; 331: 261-264.
22. Kreder HJ, Armstrong P. A review of open tibia fractures in children J Pediatr Orthop. 1995; 15: 482–488.
23. Robertson P, Karol LA, Rab GT. Open fractures of the tibia and femur in children. J Pediatr Orthop. 1996; 16: 621-626.
24. Bartlett CS 3rd, Weiner LS, Yang EC. Treatment of type II and type III open tibia fractures in children. J Orthop Trauma. 1997; 11: 357-362.
25. Song KM, Sangeorzan B, Benirschke S, Browne R. Open fractures of the tibia in children. J Pediatr Orthop. 1996; 16: 635–639.
26. Qidwai SA. Intramedullary Kirschner wiring for tibia fractures in children. J Pediatr Orthop. 2001; 21: 294-297.
27. Myers SH, Spiegel D, Flynn JM. External fixation of high-energy tibia fractures. J Pediatr Orthop. 2007; 27: 537-539.
28. Srivastava AK, Mehlman CT, Wall EJ, Do TT. Elastic stable intramedullary nailing of tibial shaft fractures in children. J Pediatr Orthop. 2008; 28: 152-158.
29. Vallamshetla VR, De Silva U, Bache CE, Gibbons PJ. Flexible intramedullary nails for unstable fractures of the tibia in children. An eight-year experience. J Bone Joint Surg Br. 2006; 88: 536-540.
30. Gordon JE, Gregush RV, Schoenecker PL, Dobbs MB, Luhmann SJ. Complications after titanium elastic nailing of pediatric tibial fractures. J Pediatr Orthop. 2007; 27: 442-446.
31. Kubiak EN, Egol KA, Scher D, Wasserman B, Feldman D, Koval KJ. Operative treatment of tibial fractures in children: are elastic stable intramedullary nails an improvement over external fixation? J Bone Joint Surg Am. 2005; 87: 1761-1768.