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Open tibial fractures in the paediatric population: a systematic review of the literature

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Introduction: Open tibial fractures have been studied extensively in adults, and detailed treatment strategies have been developed: wound irrigation and debridement, fracture stabilization and delayed primary wound closure or early flap coverage are basic principles of management. No clear guidelines regarding the management of open tibial fractures in children exist.

Sources of data: We searched Medline, Embase, Cochrane, CINAHL and Google Scholar databases using the keywords: 'open', 'tibia', 'fracture', 'children', 'paediatric', 'pediatric', 'external fixation', 'nailing'. Fourteen clinical studies were included. Quality of the studies was assessed using the Coleman Methodology Score.

Areas of agreement: Age above 10 years and grade III (severe) open fractures are associated with complications and outcomes similar to those in adults.

Areas of controversy: It is unclear whether open fractures of the tibia in children should be managed according to the principles followed in adults. Many authors support primary skin closure and non-operative management for grade I open fractures. There is no clear effect of fracture fixation method on time to union.

Growing points: The quality of the studies was relatively poor. Patients' age affects outcome; adolescents should probably be managed as adults.

Areas timely for developing research: Carefully designed prospective cohort studies including a large number of children would be of value. Adequate follow-up is necessary to assess the long-term effects in the growing skeleton. The efficacy of flexible intramedullary nailing for open fractures needs further evaluation. Outcome studies based on general health measures are needed.

Keywords: open/fracture/tibia/children/paediatric

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Introduction

Open tibial fractures in adults have been studied extensively, and numerous publications have detailed treatment strategies and outcomes.[1,2] The basic principles of management are wound irrigation and debridement, fracture stabilization and delayed primary wound closure or early flap coverage.[2] In the paediatric population, open fractures account for ~5% of all tibia fractures.[3,4] However, these injuries have not been thoroughly investigated, and clear guidelines do not exist. Although most closed tibial fractures in children can be managed non-operatively,[3,4] it is not clear whether open injuries 'behave' in a similar fashion to the adult population.[5,6] The current study assessed the published literature on open tibial fractures in children. Pooling of data was performed where appropriate, to identify the management strategies that have been applied and summarized the outcomes.

Methods

Literature search and data extraction

We conducted a comprehensive literature search using Medline, Embase, Cochrane, CINAHL and Google Scholar, without time limits. We used different combinations of the keywords: 'open', 'tibia', 'fracture', 'children', 'paediatric', 'pediatric', 'external fixation', 'nailing'. All articles relevant to the subject were retrieved, and their bibliographies searched by hand to identify further work in this field. Only articles published in peer-reviewed journals reporting on more than 10 open tibia fractures in children were included (inclusion criteria). Articles not mentioning outcomes, case reports, descriptions of surgical techniques and articles not distinguishing data between tibia and other open fractures, or between open and closed fractures of the tibia, (exclusion criteria) were excluded. Care was taken not to double-count patients and fractures appearing in different publications.

Quality assessment

Two authors independently scored the quality of the studies using the Coleman Methodology Score (CMS).[7,8] The Coleman scoring system is a method of analysing the quality of the studies reviewed, is accurate and reproducible in systematic reviews and has been used successfully for several years. It has been validated within our research centre. The CMS was adapted (Table 1) to evaluate studies reporting on open

Table 1 Criteria used to compute the Coleman Methodology Score (CMS) for studies reporting the outcomes of open tibial fractures in children.

S. no.	Part A: only one score to be given for each of the seven sections		Score
1	Study size—number of TARs	<20	0
		20–49	4
		50–99	7
		>99	10
2	Mean follow-up	<1 year	0
		1–2 years	4
		2–5 years	7
		>5 years	10
3	Number of different fracture stabilization techniques used	Not stated, unclear, or <90% of subjects receiving same technique	0
		More than one techniques, but >90% of subjects receiving one technique	7
		One technique used	10
4	Type of study	Retrospective cohort study	0
		Prospective cohort study	10
		Randomised control trial	15
5	Description of indications/diagnosis (e.g. fracture grade)	No	0
		Yes	5
6	Descriptions of surgical technique	Inadequate (not stated, unclear)	0
		Fair (technique only stated)	3
		Adequate (technique stated, details of surgical procedure given)	5
7	Postoperative management described	No	0
		Yes	10
	Part B: scores may be given for each option in each of the 3 sections if applicable		
1	Outcome criteria	Outcome measures clearly defined	2
		Timing of outcome assessment clearly stated	2
		Use of outcome criteria that has reported reliability	3
		General health measure included	3
2	Procedure of assessing outcomes	Subjects recruited	5
		Investigator independent of surgeon	4
		Written assessment	3
		Completion of assessment by patients themselves with minimal investigator assistance	3
3	Description of subject selection process	Selection criteria reported and unbiased Recruitment rate reported	5
		<90%	0
		>90%	5

tibial fractures in children. It assesses the methodology using the 10 criteria, giving a total score between 0 and 100. A score approaching 100 indicates that the study has a robust design and largely avoids chance, various biases or confounding factors. A score >85 is considered excellent, 70–84 good, 50–69 moderate and <50 poor. The subsections which compose the Coleman methodology score are based on the subsections of the CONSORT statement (for randomized, controlled

trials),[9] but are modified to allow for other trial designs. Both investigators (N.G. and A.K.) scored the quality of the studies independently. Each investigator scored the quality of the studies twice, with a time interval of 3 weeks between measurements. Intra- and inter-observer reliabilities were examined. Where differences were encountered, agreement was achieved by consensus. The presented scores are those that were set by agreement of both examiners. We collected data for the year of publication, the type of study, patient numbers, gender, the mechanism of injury, follow-up, the type of fracture, interventions, time to union, complications and outcome. Where possible, pooling of data was undertaken and 95% confidence intervals were calculated.

Statistical methods

To assess the reliability of quality scoring using the CMS, intraclass correlations for interobserver and the Spearman–Brown coefficient for intraobserver reliability were used. Student's *t*-test was used to compare the means of CMS between the two examiners. Confidence intervals (CI 95%) were calculated where pooling of data was appropriate. Level of statistical significance was 0.05. We used SPSS version 11.0 for Windows (SPSS Inc., Chicago, IL, USA) for statistical analyses.

Results

Studies

Of 241 studies, 203 were not relevant to the subject at hand. Fifteen studies met the exclusion criteria, and 13 did not meet the inclusion criteria, leaving for review 14 studies[5,6,10–21] published from 1992 to 2008. Only one study reported on children who have been treated after 2000.[21] The remaining studies reported on children treated from 1971 to 1999. Eight studies were performed in institutions in the USA,[5,14–19,21] two in Canada,[12,13] two in the UK,[6,11] one in Australia[10] and one in Saudi Arabia.[20] Thirteen were retrospective investigations[5,7,10–16,18–21] (level IV evidence)[22], and one was a combination of retrospective and prospective review of patients[17] (level IV evidence).[22]

Quality assessment

The mean CMS for the 14 studies was 40.6 of 100 (SD = 5.3, range 28–49), indicative of poor methodological quality. Each examiner

performed the assessment twice as described in the Methods section. Intraobserver Spearman–Brown coefficient was 0.94 for examiner A and 0.90 for examiner B (substantial agreement).[23] The values of the second assessment for each examiner were included for further evaluation. There was no significant difference between the mean CMS of the two examiners (40.6 compared with 39.2, $P = 0.48$). The intraclass correlation was 0.87, indicative of substantial agreement between the two examiners.[23] Disagreement occurred in eight studies (in one variable in seven studies, and in two variables in one study). After substantial agreement was obtained, the values presented are those set by agreement between the two examiners. Quality scores were poor in all studies. There was no disagreement regarding grading of the quality of the studies between the two examiners. Eight studies provided a mean follow-up of more than 1 year and six studies did not provide mean follow-up data. Only five studies recruited patients for review. The remaining eight studies retrospectively reviewed patients' medical records. None of the studies included a validated outcome measure, and none included a general health quality measure. Only one study assessed the social impact of open tibial fractures in children (days absent of school, need to repeat a year, limp at follow-up).

Demographic data and perioperative details

Fourteen studies reported on 714 skeletally immature patients treated for an open tibial fracture between 1972 and 2005. The mean age of 660 patients was 9.4 years (range 2–17, 95% CI 9.0–9.9) at the time of injury. Two studies[17,20] reporting on 54 patients did not provide data on patients' mean age. Of 643 children, 476 were boys (74%) and 167 girls (26%). Two studies[18,19] reporting on 71 patients did not mention patients' gender. The most common cause of the injury in 621 patients was a motor vehicle hitting a pedestrian or a bicycle (76%, with CI 95% 0.612–0.822), with three studies[17,19,20], reporting on 93 patients, not providing relevant data . The tibial fracture was the only injury in 302 of 497 patients (61% with CI 95% 0.509–0.706), according to eight studies.[5,6,10,11,13–15,21] Table 2 describes the severity of open fractures according to the Gustilo–Anderson classification.[24,25] Only eight studies[5,6,13,14,16,18–20] reporting on 437 patients presented satisfactory follow-up data. The mean follow-up for those patients was 13.2 months (95% CI 12.2–14.2). Three studies,[6,18,19] although describing different methods of fracture management, did not give numerical data. In the remaining 11 studies, reporting on a total of 605 fractures, several techniques for fracture stabilization were used. In nine patients with IIIC open fractures, and a non-salvagable mangled

Table 2 Methods of fracture stabilization in 605 open tibial fractures.[5,6,10–15,17,20,21]

Method	Fractures, *n* (%)	95% CI
Cast	313 (51.7)	0.331–0.703
External fixation	163 (26.9)	0.102–0.337
Internal fixation (any form)	58 (9.6)	0.000–0.264
Steinman pins and plaster	40 (6.6)	0.000–0.148
Elastic IMN	20 (3.3)	0.000–0.203
Skeletal traction	2 (0.3)	0.000–0.009
Primary amputation	9 (1.5)	0.000–0.030
Total	605 (100)	

CI, confidence interval; IMN, intramedullary nailing.

Table 3 Classification of open fractures in children according to Gustillo–Anderson.[24,25]

	Fractures	Mean incidence (%)	95% CI
I	227/714[5,6,10–21]	31.8	0.253–0.383
II	270/714[5,6,10–21]	37.8	0.327–0.429
III	213/714[5,6,10–21]	29.8	0.212–0.384
Not classified	4/714[5,6,10–21]	0.6	0.000–0.014
IIIa	98/683[5,6,10–17,19–21]	14.3	0.088–0.199
IIIb	67/683[5,6,10–17,19–21]	9.8	0.041–0.155
IIIc	18/683[5,6,10–17,19–21]	2.6	0.007–0.046

CI, confidence interval.

Table 4 Open wound management.

	Fractures	Mean incidence (%)	95% CI
Delayed primary wound closure	222/683[5,6,10–17,19–21]	32.5	(0.182–0.468)
Flap or skin graft required	100/521[5,6,11–17]	19.2	(0.099–0.284)

CI, confidence interval.

extremity, an amputation was performed (Table 3). Data regarding the open wound management are presented in Table 4. The status of the fibula (broken or intact) and the tibia configuration of the fracture (e.g. transverse, oblique, spiral, multifragmented, diaphyseal vs. metaphyseal) in relation to the stabilization technique that was selected were not reported in the original studies.

Outcome

The mean time to union in the 714 fractures[5,6,10–21] was 15.3 weeks (95% CI 14.3–16.3). Table 5 summarizes the pooled data regarding complication rates. Amputation was required in 11 of 19 (57.8%) type IIIc open fractures. None of grade I or grade II open fractures required an amputation. Six studies[10,12,13,15,16,18] found an association

Table 5 Complications in open tibial fractures in children.

	Fractures	Mean incidence (%)	95% CI
Non-unions	32/683[5,6,10–17,19–21]	4.7	0.024–0.070
Delayed unions	87/683[5,6,10–17,19–21]	12.7	0.071–0.183
Malunions	45/683[5,6,10–17,19–21]	6.6	0.033–0.099
LLD	63/683[5,6,10–17,19–21]	9.2	0.021–0.164
Neurovascular	30/683[5,6,10–17,19–21]	4.4	0.019–0.066
Compartment syndrome	19/643[5,6,10–17,20,21]	3.0	0.014–0.045
Infections	43/714[5,6,10–21]	6.0	0.033–0.087
Amputations	11/714[5,6,10–21]	1.5	0.002–0.028
Deaths	11/714[5,6,10–21]	1.5	0.002–0.029

CI, confidence interval; LLD, leg-length discrepancy.

between older age and longer time to fracture healing. Eight studies[5,6,10–12,15,16,18] related higher grade open fractures with a higher complication rate and longer times to union. Pooling data in 10 studies providing relevant information,[5,6,10–16,21] we found that 209 grade I open fractures healed at a mean of 10.3 weeks (95% CI 9.9–10.7), 248 grade II fractures at 12.8 weeks (95% CI 12.2–13.4) and 157 grade III fractures at 20.7 weeks (95% CI 18.1–23.3). However, differences in time to union between grade I and II fractures and grade II and III fractures were not significant ($P = 0.50$ and 0.06 respectively). Differences in time to union were significantly different between fractures of grades I and III ($P = 0.04$).

Discussion

The literature describing treatment and outcomes of open tibial fractures in children is of poor quality. It consists mostly of retrospective analyses based on patients' medical records review. No validated outcome measures have been used. The necessity of general health measures to present clinical outcome was probably not recognized when most of the studies were published. Assessment questionnaires have not been used, and the outcome assessments were not performed by independent investigators. Presentation of data was performed in a non-systematic way, and different treatments were applied for the same condition without specific protocols. Correlation of outcomes and complications to the severity of the injury, to patients' age or to the treatment itself was not always performed. The published studies do not allow one to draw scientifically based conclusions of management strategy, or to identify risk factors. Finally, there is lack of long-term follow-up studies despite the fact that these injuries in the paediatric

population can lead to angular deformity and leg length discrepancy (7.3 and 10% in the short term, respectively).

Despite these scientific weaknesses, pooling of data revealed some useful information. Open tibial fractures in children are frequently caused by motor vehicles hitting pedestrians or bicycles, and are not the only injury in about 40% of cases. They are associated with a 4.5% incidence of neurovascular compromise requiring intervention, 1.5% primary amputation and 1.2% mortality rates. Repeated wound debridement and secondary plastic surgery is required in about 20% of fractures. This should raise awareness regarding the severity of these injuries.

It is unclear whether open fractures of the tibia in children should be managed according to the principles followed in adults. For example, should wounds be left open after debridement and the fracture stabilized by operative intervention, as is recommended in adults? Is a better healing potential in children sufficient to justify a more conservative fracture management approach? Is selective primary wound closure appropriate to avoid repeated surgical interventions in the paediatric population? The weaknesses characterizing the available evidence (lack of defined prospective protocols and poor scientific quality of published studies) do not allow us to draw definitive conclusions. There is, however, a trend towards better results in younger children and low Gustilo–Anderson fracture grade.[24,25]

The vast majority of open tibial fractures included in this review were treated from 1971 to 1994. This may explain the use of cast immobilization in more than half of the fractures and the infrequent use of elastic intramedullary nailing. There are no published studies to confirm a trend towards more frequent operative stabilization of these fractures during the subsequent years. The mean incidence of grade III open tibial fractures in children was 28.5%. This is less than the 57% incidence in adults reported by an epidemiological study,[26] and represents a favourable situation regarding healing in children. Open tibial fractures in children occurred in combination with other injuries in 40% of cases. This is comparable with a 53% incidence of other injuries documented in adults.[26] Regarding the observed complication in comparison to those in adults, an overall 6% deep infection is lower than the 7–35% reported for different fracture fixation methods in adults.[1] The non-union rate of 4.7% is, however, comparable with that in the adult population,[1] whereas delayed union is more frequent in adults (14–38%).[1] Angular malunion rate was 6.6% in children when compared with 4–20% in adults.[1] The lower incidence of compartment syndrome in children (3%) when compared with adults (9–10%)[27,28] may reflect the lower incidence of grade III open fractures. Vascular complications are comparable with the reported

rate of approximately 4% in adults.[29] We found that 58% of the extremities with 17 IIIc open tibial fracture in children were not salvageable despite the presumed favourable biology of this age group. This incidence is probably comparable with a 50–73% amputation rate in adults with IIIc type open fractures.[30,31] A mean healing time of 20.7 weeks in grade III open fractures is lower than the 28 week mean time to union reported in a cohort of 73 IIIb open tibial fractures in adults.[28]

The age of the children with an open tibial fracture influenced the outcome in some studies.[10,12,13,15,16,18] Younger age (<10 years) was generally associated with more rapid fracture union and a lower rate of complications. This suggests that, when treating open tibia fractures, it is appropriate to distinguish between younger and older children. The age of 10 years may serve as a watershed for this purpose. Remodelling and overgrowth associated with fracture healing in children occur to a lesser degree in older children. Higher fracture grades according to the Gustilo classification were also associated with worse results.[5,6,10–13,15,16,18] The available literature shows that open wounds in grade I open fractures in younger children can be treated with primary closure after irrigation and debridement. Grade I open injuries are probably caused by inside—out trauma, and represent a favourable scenario.[32] Given the high healing potential in children, these are probably the only soft-tissue injuries that can be managed with primary closure after irrigation. If the fracture is reducible, stable plaster cast immobilization is a reliable method of treatment. Unstable grade I and grade II fractures can be possibly safely managed with external fixation or elastic intramedullary nailing.[1]

Grade 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. The option of external fixation seems appropriate for the management of grade III open fractures, and the use of elastic intramedullary nailing may become even more popular in years to come. Grade III fractures are associated with healing time, complications and amputation rates comparable with those in adults. Although we could assume that high-grade open fractures are more common in older children and adolescents, it is unclear from the data available which is the detrimental factor influencing outcome.

Open tibial fractures in children are an orthopaedic challenge. Further research is needed to improve our understanding of the interaction between age, severity of injury, concomitant injuries, type of fracture fixation and soft-tissue management as they relate to outcome. Randomized studies in open fracture management are difficult to

conduct, and may probably be unethical. It is difficult to enrol large enough patient numbers to allow randomization between different treatments. Multiple variables (e.g. age, soft-tissue conditions, multiple injuries, head injury) can influence results and, frequently, concomitant injuries influence treatment. Therefore, carefully designed prospective, cohort, multicentre studies including a large number of children with open or closed tibial fractures would be of value. Clear criteria and indications for treatment should be followed, and documentation of several variables (e.g. soft-tissue condition, concomitant injuries, fracture configuration, timing of surgery) should be included. Patients should be assessed regarding time to union, complications and need for re-operations. They should be evaluated radiographically and clinically at appropriate time intervals. A general health questionnaire would be essential, and assessment of social factors, absence from school, and return to sports should be performed. Adequate follow-up would be necessary to assess the long-term effects in the growing skeleton.

Conclusions

The quality of studies reporting on open tibia fractures in the paediatric population is poor. Complication rates are not unremarkable. Age >10 years and grade III (severe) open fractures are associated with complications and outcomes similar to those in adults. It was not possible to demonstrate an effect of the fracture fixation method on time to union. Better quality prospective studies are required to quantify the effects of different treatments.

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