The AO Pediatric Comprehensive Classification of Long Bone Fractures (PCCF)

Laurent Audigé, Theddy Slongo, Nicolas Lutz, Andrea Blumenthal & Alexander Joeris

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Part III: Multifragmentary long bone fractures in children—a retrospective analysis of 2,716 patients from 2 tertiary pediatric hospitals in Switzerland

Laurent AUDIGÉ [1,2], Theddy SLONGO [3], Nicolas LUTZ [4], Andrea BLUMENTHAL [1], and Alexander JOERIS [1]

[1] AO Clinical Investigation and Documentation, Dübendorf; [2] Schulthess Clinic, Research and Development Upper Extremities, Zürich; [3] Department of Pediatric Surgery, Traumatology and Orthopedics, University Hospital (Inselspital), Bern; [4] Centre Hospitalier Universitaire Vaudois (CHUV), Lausanne, Switzerland.
Correspondence: alexander.joeris@aofoundation.org
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Background and purpose — **The AO Pediatric Comprehensive Classification of Long Bone Fractures (PCCF) describes the localization and morphology of fractures, and considers severity in 2 categories: (1) simple, and (2) multifragmentary. We evaluated simple and multifragmentary fractures in a large consecutive cohort of children diagnosed with long bone fractures in Switzerland.**

Patients and methods — **Children and adolescents treated for fractures between 2009 and 2011 at 2 tertiary pediatric surgery hospitals were retrospectively included. Fractures were classified according to the AO PCCF. Severity classes were described according to fracture location, patient age and sex, BMI, and cause of trauma.**

Results — **Of all trauma events, 3% (84 of 2,730) were diagnosed with a multifragmentary fracture. This proportion was age-related: 2% of multifragmentary fractures occurred in schoolchildren and 7% occurred in adolescents. In patients diagnosed with a single fracture only, the highest percentage of multifragmentation occurred in the femur (12%, 15 of 123). In fractured paired radius/ulna bones, multifragmentation occurred in 2% (11 of 687); in fractured paired tibia/fibula bones, it occurred in 21% (24 of 115), particularly in schoolchildren (5 of 18) and adolescents (16 of 40). In a multivariable regression model, age, cause of injury, and bone were found to be relevant prognostic factors of multifragmentation (odds ratio (OR) > 2).**

Interpretation — **Overall, multifragmentation in long bone fractures in children was rare and was mostly observed in adolescents. The femur was mostly affected in single fractures and the lower leg was mostly affected in paired-bone fractures. The clinical relevance of multifragmentation regarding growth and long-term functional recovery remains to be determined.**

The AO Pediatric Comprehensive Classification of Long Bone Fractures (PCCF), which was adapted from the AO/OTA classification (Audigé et al. 2004, Slongo et al. 2006, 2007), initially included a similar concept of 3 classes of fracture severity, defined as (1) simple, with no intermediate bone fragment at the fracture site, (2) wedge, and (3) complex. Validation data, however, suggested that the classes wedge and complex should be merged (Slongo et al. 2007a) because there were few complex fractures documented in the consecutive collection of cases used for evaluation. As there was limited clinical relevance in further distinguishing fracture severity in children, the current system considers 2 classes: (1) simple and (2) multifragmentary (wedge or complex).

The Lila classification, an alternative system that differs from the PCCF, defines fragmentation as being when more than 1 intermediate fragment is identified at the fracture site (Schneidmuller et al. 2011). In addition, the Lila classification does not classify fragmentation as intra-articular or extra-articular fractures.

We documented epidemiological data involving 2,840 long bone fractures in 2,716 children and adolescents younger than 17 years of age in 2 Swiss hospitals (Joeris et al. 2014). While fracture patterns in the same study cohort have been described in 2 companion papers (Joeris et al. 2016a, b), the present analysis focuses on description of the frequency, location, and distribution of multifragmentary fractures. In addition, we investigated possible risk factors that may be associated with the occurrence of multifragmentary fractures.

Patients and methods

Consecutive fractures in children sustained over 2 years at 2 Swiss university children's hospitals (Joeris et al. 2014) were
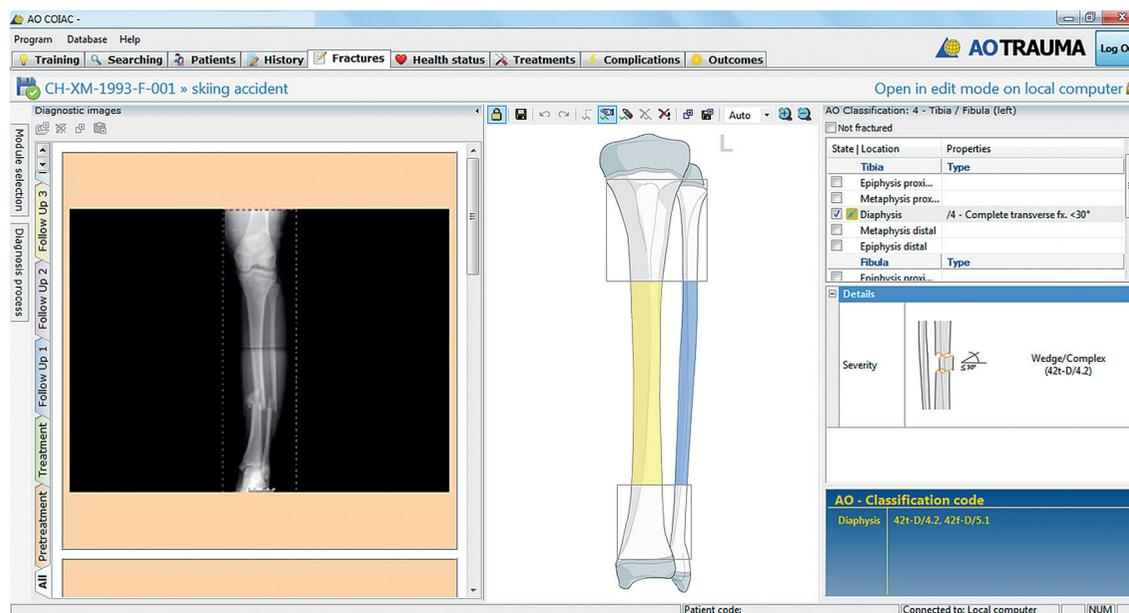
Screenshot of the AOCOIAC interface with documentation of a multifragmentary tibial fracture caused by a skiing accident.

retrospectively documented and classified according to the AO PCCF system (Slongo et al. 2006, 2007b) using AOCOIAC (Figure) (Joeris et al. 2016a). Fracture severity was either defined as: (1) simple, with 2 main fracture fragments, or (2) multifragmentary (i.e. wedge or complex), with 2 main fracture fragments and at least one-third, fully separated intermediate fragment (Slongo et al. 2007c). By definition, multifragmentation only applies to specific subcategories, for instance torus/buckle fractures, Salter-Harris type-I (SH I) fractures, greenstick fractures, and ligament avulsions are considered to be simple fractures where no coding of severity applies (Slongo et al. 2007b).

Epidemiological data including age, sex, BMI, date of injury, mechanism of injury, and cause of injury were extracted from the medical records when available. The patients were classified into 4 age groups and 5 BMI categories, as described previously (Joeris et al. 2014) (www.who.int/childgrowth/standards/bmi_for_age/en/).

Statistics

Data management and analyses were implemented using Intercooled Stata software version 14. Simple and multifragmentary fractures were cross-tabulated using absolute and relative frequencies, according to the fracture location (bones and sub-segments) and age classes, separately in patients with single fractures and in patients with either both tibia and fibula (lower leg) fractured or radius and ulna (forearm) fractured (hereon referred to as "combined fractures in paired bones"). Other combined fractures were also documented regarding fragmentation.

The factors sex, age at time of accident (combining infants, toddlers, and pre-school children in one class), BMI

(combining severe thinness and thinness), cause of injury (home, leisure activity, traffic, and other causes), and bone were explored as prognostic factors for bone fracture multifragmentation using logistic regression modeling. For this analysis, we included only the first trauma event of any child that resulted in a single fractured bone. Factors were first analyzed separately using univariable regression, then combined (except BMI) into a multivariable model. Model misspecification was checked using the "linktest" command in Stata and the goodness of fit of the model was tested using the Hosmer-Lemeshow test. Any factor with at most a weak association with the outcome (i.e. with an odds ratio (OR) of below 2) was removed from the final model, if this improved the fit of the model. Standardized residuals were investigated for the presence of strongly influential outliers. The database included an adequate number of 19 events (multifragmentation in fractured bones) per factor. BMI was only analyzed at the univariable level with a reduced database, considering patients from Bern for whom the BMI was available. All analyses were considered to be explorative and descriptive. Results are presented as OR and interpreted as relative risks, given the fact that the prevalence of multifragmentation in children's fractures is low.

Results

The study cohort has been described in detail in a previous report (Joeris et al. 2014). 2,840 fractures involving 2,730 trauma events in 2,716 patients (60% boys) were documented, including 176 infants (6%), 699 pre-school children (26%), 1,074 schoolchildren (40%), and 767 adolescents (28%). 51

Table 1. Multifragmentation of single long bone fractures, shown according to age class, bone, and bone sub-segment

Bone	Sub-segment	Infants/toddlers (< 2 years)		Pre-school children (2 to < 6 years)		School-children (6 to < 11 years)		Adolescents (11–17 years)		All	
		Si	Mu	Si	Mu	Si	Mu	Si	Mu	Si	Mu
Humerus	E proximal	-	-	2	1	7	-	17	1	26	2
	M proximal	2	-	14	-	29	2	26	3	71	5
	D	2	-	8	-	4	-	10	1	24	1
	M distal	18	-	154	-	158	3	18	2	348	5
	E distal	1	-	41	1	27	1	14	5	83	7
Radius	E proximal	-	-	2	-	11	-	3	1	16	1
	M proximal	1	-	1	-	20	-	11	-	33	-
	D	1	-	10	-	14	-	7	-	32	-
	M distal	32	-	106	-	345	-	193	-	676	-
	E distal	-	-	1	-	33	-	49	-	83	-
Ulna	E proximal	-	-	-	-	-	-	-	-	-	-
	M proximal	1	-	23	-	8	-	11	-	43	-
	D	-	-	15	-	17	-	5	-	37	-
	M distal	3	-	-	-	4	-	4	-	11	-
	E distal	-	-	-	-	-	-	1	-	1	-
Femur	E proximal	-	-	-	-	-	-	1	-	1	-
	M proximal	1	-	2	-	-	-	3	1	6	1
	D	10	-	30	-	16	6	14	7	70	13
	M distal	10	-	3	-	7	-	3	-	23	-
	E distal	-	-	1	-	3	1	4	-	8	1
Tibia	E proximal	-	-	2	-	5	-	6	1	13	1
	M proximal	10	-	9	-	1	-	3	-	23	-
	D	2	-	32	-	39	1	13	2	86	3
	M distal	9	-	5	-	1	-	5	-	20	-
	E distal	-	-	-	-	6	-	29	-	35	-
Fibula	E proximal	-	-	-	-	-	-	-	-	-	-
	M proximal	-	-	-	-	-	-	-	-	-	-
	D	3	-	-	-	-	-	1	2	4	2
	M distal	1	-	1	-	-	-	-	1	2	1
	E distal	-	-	5	-	36	-	19	-	60	-
All bones and location		107	0	467	2	791	14	470	27	1,835	43
(%)		100	0	99.6	0.4	98.3	1.7	94.6	5.4	97.7	2.3

Si:simple; Mu: multifragmentary; E: epiphyseal; M: metaphyseal; D: diaphyseal.

patients sustained more than 1 fracture during the same accident, either in the same bone (n = 20) or in different bones (n = 31). 27% of patients (210 of 791) for whom the BMI was available were categorized as either overweight or obese. Long bone fractures mainly involved the forearm (59%), followed by fractures of the upper arm (21%), the lower leg (15%), and the femur (5%).

Overall, 3% of the trauma fracture events (84 of 2,730) were diagnosed as having a multifragmentary fracture. In trauma events associated with a single long bone fracture, multifragmentation occurred in 2% of cases (43 of 1,878). However, the proportion of multifragmentary fractures in the latter patient group increased with age (p < 0.001) and was 0.3% (2 of 576) in children less than 6 years of age, 2% in schoolchildren, and 5% in adolescents (Table 1).

Multifragmentation in single bones occurred in 81% of the cases in the femur and the humerus (35 of 43). In the femur, multifragmentation occurred in 12% of all femoral fractures (15 of 123), mostly in the diaphysis (13 of 15 fractures). In the humerus, multifragmentation occurred in 4% of all humeral fractures (20 of 572), mainly in the distal epiphysis (7 of 20 fractures), followed by the distal metaphysis (5 of 20 fractures) and the proximal metaphysis (5 of 20 fractures). Multifragmentation of 1 bone only was rarely observed in the radius, the tibia, and the fibula (radius: 1; tibia: 4; fibula: 3). It was never encountered in the ulna (Table 1).

In combined fractures of paired bones, a higher proportion of multifragmentary fractures was observed in the tibia and fibula (21%, 24 of 115) than in the radius and ulna (2%, 11 of 698) (p < 0.001) (Tables 2 and 3). Most of the combined multifragmentary tibial and fibular fractures were observed in schoolchildren (5 of 18) and adolescents (16 of 56); two-thirds involved the tibial diaphysis.

Multifragmentation was also diagnosed in 4 of 31 trauma events that caused fractures in more than 1 bone: 2 events caused combined fractures of the humerus and paired radius/

Table 2. Multifragmentation of combined radial and ulnar fractures, shown according to age class and bone sub-segment

Age class [a] Radius	Ulna	Si	Mu	%
Infants and toddlers				
M proximal	M proximal	1	–	
D	D	9	1	
M distal	M distal	24	–	
		34	1	3
Pre-school children				
E proximal	M proximal	1	–	
M proximal	M proximal	9	–	
M proximal	D	2	–	
D	D	69	1	
D	M distal	9	–	
M distal	D	4	–	
M distal	M distal	96	–	
M distal	E distal	1	–	
E distal	M distal	5	–	
E distal	E distal	1	–	
		197	1	0.5
Schoolchildren				
E proximal	M proximal	2	–	
M proximal	M proximal	2	–	
M proximal	D	1	–	
D	M proximal	1	–	
D	D	57	1	
D	M distal	4	–	
M distal	M proximal	1	–	
M distal	D	1	–	
M distal	M distal [b]	152	–	
M distal	E distal	20	–	
E distal	M distal	7	2	
E distal	E distal	10	.–	
		258	3	1.1
Adolescents				
D [c]	D	22	3	
D	M distal	4	–	
M distal	D	1	–	
M distal	M distal [b]	63	1	
M distal	E distal	63	1	
E distal	M distal	3	–	
E distal	E distal	42	1	
		198	6	2.9
All patients		687	11	1.6

[a] For ages in age classes, see Table 1
[b] One patient in each age group had a third fracture in the distal epiphysis of the ulna, with all 3 fractures being simple.
[c] One patient had a third fracture in the distal metaphysis of the radius. All fractures were simple.
Si: only simple fractures; Mu: at least 1 multifragmentary fracture.
%: proportion of multifragmentary fractures.
E: epiphysea; M: metaphyseal; D: diaphyseal.

Table 3. Multifragmentation of combined tibial and fibular fractures, shown according to age class and bone sub-segment

Age class [a] Tibia	Fibula	Si	Mu	%
Infants and toddlers				
D	D	2	–	
D	M distal	1	–	
M distal	D	2	–	
M distal	M distal [b]	9	–	
		14	0	0
Pre-school children				
M proximal	M proximal	4	–	
D	D	9	1	
D	M distal	1	–	
M distal	D	1	–	
M distal	M distal	9	2	
		24	3	11
Schoolchildren				
D	M proximal	2	1	
D	D	6	3	
D	M distal	1	1	
M distal	M proximal	1	–	
M distal	M distal	1	–	
E distal	E distal	2	–	
		13	5	28
Adolescents				
E proximal [c]	M distal	1	–	
M proximal	M proximal	–	1	
D	M proximal	–	1	
D	D	14	4	
D	M distal	3	3	
M distal	M distal	3	3	
E distal	D	–	1	
E distal	M distal	13	3	
E distal	E distal	6	–	
		40	16	29
All patients		91	24	21

[a] For ages in age classes, see Table 1
[b] One patient had a third fracture in the distal epiphysis of the fibula.
[c] One patient had a third fracture in the distal epiphysis of the tibia.
Si: only simple fractures; Mu: at least 1 multifragmentary fracture.
%: proportion of multifragmentary fractures.
E: epiphyseal; M: metaphyseal; D: diaphyseal.

ulna on the same side; 1 event led to combined fractures of the humerus and the paired tibia/fibula bones on the same side; the last event triggered 2 tibial fractures with a fibular fracture plus an additional femur fracture on 1 side and a tibial fracture on the other side. The patients involved were of school age or older.

In a univariable logistic regression model, sex showed (at best) a weak association with the occurrence of fracture multi-fragmentation (p = 0.5) (Table 4). This factor was also removed from the multivariable model, resulting in an improved fit of the model to the data. Model specification appeared adequate and no strongly influential outlier in the model was identified. Schoolchildren were 4 times more likely and adolescents were 12 times more likely to have multifragmentation than younger patients (p < 0.001). After considering the factor age, events occurring during leisure activities and traffic accidents did not appear to be more likely to cause multifragmentation than accidents at home (leisure activities: OR = 1.0; traffic accidents: OR = 1.2; p ≥ 0.7). Femoral fractures were 33 times more likely and tibial/fibular fractures were 12 times more likely to have multifragmentation than radial/ulnar fractures. Humeral fractures were 9 times more likely to have multifrag-mentation than radial/ulnar fractures (p < 0.001).

Patients with BMI in the normal or overweight range appeared to be at about twice the risk of having fracture mul-

Table 4. Factors associated with multifragmentation in pediatric long bone fractures [a]

Factors	Si	Mu	%	Univariable OR (95% CI)	p-value	Multivariable [b] OR (95% CI)	p-value
Sex							
Girl	1,024	28	2.7				
Boy	1,513	49	3.1	1.2 (0.74–1.9)	0.5		
Age at time of injury					< 0.001		< 0.001
Infants, toddlers/pre-school	823	7	0.8				
Schoolchildren	1,029	21	2.0	2.4 (1.0–5.7)	0.05	3.9 (1.6–9.6)	0.004
Adolescents	685	49	6.7	8.4 (3.8–19)	< 0.001	12 (5.0–29)	< 0.001
Cause of injury					< 0.001		0.006
Home accident	342	8	2.3				
Leisure activity	620	34	5.2	2.3 (1.1–5.1)	0.03	1.0 (0.4–2.4)	1.0
Traffic accident	275	14	4.8	2.2 (0.9–5.3)	0.08	1.2 (0.4–3.1)	0.7
Other causes [c]	1,300	21	1.6	0.7 (0.3–1.6)	0.4	0.4 (0.2–1.0)	0.05
Bone					< 0.001		< 0.001
Radius/ulna	1,576	11	0.7				
Humerus	532	21	3.8	5.7 (2.7–12)	< 0.001	8.9 (4.2–19)	< 0.001
Femur	103	16	13.5	22 (10–49)	< 0.001	33 (14–76)	< 0.001
Tibia/fibula	326	29	8.2	13 (6.3–26)	< 0.001	12 (5.9–25)	< 0.001
Body mass index [d]					0.6		
Severely thin/thin	91	2	2.2				
Normal	455	23	4.8	2.3 (0.5–9.9)	0.3		
Overweight	113	5	4.2	2.0 (0.4–11)	0.4		
Obese	83	5	5.7	2.7 (0.5–15)	0.2		

[a] In the full dataset, there were 84 children with 2 trauma events, 2 with 3 events, and one with 4 events. Furthermore, 2 bones were fractured during the same trauma event in 29 children and 3 bones in 2 children. For this analysis, only trauma events causing fracture(s) in a single bone or paired bones (tibia/fibula and radius/ulna), and only the first trauma event in any child were included.

[b] In the full model, the factor sex showed no association with fracture multifragmentation, with an OR of 0.8 (95% CI: 0.5–1.4; p = 0.5). Removal of this factor improved the goodness of fit of the model (Hosmer-Lemeshow, p = 0.2) with negligible effect on other factors, so the final model is presented without "sex".

[c] This category combines: school, 4/218 (1.8%); playground, 3/297 (1.0%); fall, 12/710 (1.7%), and other causes 2/96 (2.1%).

[d] BMI data in children > 2 years of age from one clinic (Bern) were categorized as previously described. 1 of 36 bone fractures in severely thin children (2.8%) was multifragmentary and 1 of 57 bone fractures in thin children was multifragmentary. Both groups were combined as a reference category for the logistic regression analysis.

Si: simple fracture; Mu: multifragmentary fracture; %: proportion of multifragmentary fractures.

tifragmentation, and obese patients were at a 3 times higher risk, compared to thin and severely thin patients, but effect estimates showed wide confidence intervals including 1.0.

Discussion

This investigation focused on multifragmentation as an indicator of fracture severity in a large cohort of children; we included all diagnosed fractures, irrespective of their treatment (Audige et al. 2005, Joeris et al. 2014). As the diagnosis of multifragmentation in children's fractures has been shown to be reliable when using routine radiographic images (Slongo et al. 2007c), the present study provides valid epidemiological data. The terms "comminution" or "comminuted" have been common when describing complex fractures presenting with multiple pieces of bone, but "multifragmentation" and "multifragmentary fracture" are more preferable specific terms for the PCCF, as in other AO fracture classification systems (Kellam and Audigé 2006, Cornelius et al. 2014).

Overall, multifragmentation is a rare feature in long bone fractures in children, and it involved only 3% of trauma events. Other published data allowed only limited comparison with our data, mostly because of differences in study populations. Using a comparable adaptation to the AO/OTA system for adults (Marsh et al. 2007) in a consecutive series of patients below 16 years of age, 13% of multifragmented fractures (30 of 232) were documented as B (wedge) or C (complex) fractures by Meling et al. (2013), but only surgically treated fractures were included. Another study using the AO/OTA pediatric system (which is the same system as the PCCF) found that between 20% and 30% of severe (multifragmentary) lower extremity fractures were caused by high-energy trauma (Gilbert et al. 2015).

The proportion of multifragmentary fractures was statistically significantly higher in adolescents (7%) and schoolchildren (2%) than in infants, toddlers, and pre-school children (0.8%). It was also highest following leisure activities and traffic accidents. These numbers and effect estimates from the multivariable model are consistent with the findings that chil-

dren (mostly schoolchildren and adolescents) are at a higher risk of high-energy trauma through leisure activities (e.g. skiing, rollerblade) or increased exposure to traffic accidents (e.g. bicycle, non-motorized scooter, and motorized scooter) (Joeris et al. 2014). As in a previous study (Gilbert et al. 2015), up to one-third of paired tibia/fibula fractures in schoolchildren and adolescents were multifragmentary. Following traffic accidents (events likely to be high-energy), 17% of the lower extremity fractures were multifragmentary in the present study. In addition, the more mature skeleton of adolescents is probably more prone to fracture fragmentation from similar trauma events than in younger children.

Only 1% of the fractures of the radius/ulna were multifragmentary. Compared to the lower extremity, this small proportion of multifragmentary fractures affecting the upper extremity supports the intuitive direct relationship between multifragmentation of the bone and the mechanism of injury, i.e. direct high-energy impact on a weight-bearing bone (Joeris et al. 2016a).

In this study, 1% of single metaphyseal fractures and 7% of diaphyseal fractures were multifragmentary. In a recent validation study of the Lila classification (Schneidmuller et al. 2011), multifragmentation was reported in none of 78 metaphyseal fractures and in 2 of 38 diaphyseal fractures. While the proportions appear to be consistent, our cohort was larger, and the definitions of multifragmentation in both systems differ.

While there is evidence in recent publications that obesity may increase the risk of fracture in children in general (Backstrom et al. 2012, Joeris et al. 2014, Kwan et al. 2014), we found no evidence for an association between obesity and increased occurrence of multifragmentation. Backstrom et al. (2012) reported that obese patients with femoral and tibial fractures were at higher risk of more severe injuries, but with no data regarding fracture multifragmentation. In another study, a trend of more severe tibial fractures was noted in obese patients (50%) than in non-obese patients (29%) with lower extremity fractures after high-energy trauma (Gilbert et al. 2015). Our analysis included upper and lower extremity fractures, but a similar relationship between obesity and fracture multifragmentation was observed when restricting the analysis to lower extremity injuries (ad hoc subgroup analysis not shown).

The clinical relevance of fracture multifragmentation in terms of patient outcome remains to be determined, but an appropriate classification of multifragmentary fractures helps in planning of adequate fracture treatment. Also, as multifragmentation in children's fractures appears to be rather rare, it should be considered to be a sign of a high-energy trauma, associated with concomitant injuries or post-treatment instability. Detection of early bone displacement requires special awareness by clinicians dealing with such fractures.

Our study has some limitations, particularly its retrospective study design. The quality of data was dependent on the completeness of the patient charts, specifically regarding the cause of injury. While we have shown the applicability of the PCCF for identification of multifragmentary pediatric fractures, further studies should attempt to determine their clinical relevance regarding treatment decisions and prognostication of outcome. Such a documentation project would be best implemented prospectively in the context of a clinical registry. In addition, prognostic studies may be implemented separately for different fracture locations.

Conclusion

Multifragmentation as defined in the PCCF is a rare morphological characteristic of long bone fractures in children. It mostly affects the femur in single bone fractures and the lower leg in paired tibia and fibula fractures, especially following high-energy trauma. The proportion of multifragmentary fractures with age (adolescents were at highest risk), whereas sex and BMI appeared to have no prognostic value.

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