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Midterm Results after Physeal Separations of the Distal Tibia with Particular Attention to Posttraumatic Growth Disturbances – A Prospective Multicenter Study

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Abstract

Background: Physeal injuries to the distal tibia are known to cause growth disorders. These may occur in the first two years after injury. Many investigations do not differentiate between physeal separations and epiphyseal fractures. This paper reports on the mid-term results including premature growth arrest in a cohort of 150 injuries.

Material and Methods: Twenty-one pediatric trauma centers were asked to contribute their subsequent cases over a period of three years, observing each case over a period up to three years prospectively.

Results: All children and adolescents returned to sports within one year after injury, but approximately one out of seven did not reach pre-trauma level of sports. We found a share of 12.7% of post-traumatic growth disorders appearing as leg length difference or axial deviation. Only 21.1% of the injured with a growth disorder or 2.7% of all participants needed surgical correction. Our rate of growth disorders and need of surgical correction is lower than in many other publications, which report growth disorders in up to over 40% and the need of secondary surgery in up to two thirds of the cases.

Discussion: Most children achieve a good result after physeal separations. We attribute our low rate of significant growth disorders to the fact, that in our series the indication for reduction and operative fixation was provided very strictly in axial deviations of more than 10 degrees primarily. The few surgically relevant growth disorders appear 12 months after injury or later. As growth disorders may appear in between the first two years after injury, a long period of observation needs to be recommended.

Conclusion: The rate of growth disorders may be reduced by initially strict indication to reduce posttraumatic axial deviations.

Keywords: Physeal separation; Distal tibia; Treatment; Follow up; Premature growth arrest

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Background

Physeal separations of the distal tibia are the second most common injuries of this type in the growing skeleton after those of the distal radius, and they are the most common of the lower extremity [1]. They have a peak age of approximately 11 to 13 years [2,3]. Growth plate displacements with a metaphyseal wedge (Salter-Harris II) are significantly more common than without (Salter-Harris I) [1,4,5]. The SH II to I ratio is about 8 to 1. The injuries are accused of being particularly responsible for the development of post-traumatic growth disorders. The frequency is stated to be between 5% and 20% depending on age [6,7]. Pediatric traumatologists with training in pediatric surgery obviously assess the risk differently to pediatric traumatologists with a background in trauma surgery [8]. The clinical effects are considered to be of rare relevance [6]. However, there are reports that state the requirement of corrective surgery in 66% of the cases due to post-traumatic growth disorders [9]. The focus is on inhibiting growth disorders that might cause premature partial or total growth plate closure. The result is almost always a varus deformity [7]. Accident mechanism, primary

degree of dislocation, inadequate post-traumatic reduction result, as well as multiple reduction maneuvers are cited as risk factors for the development of premature physeal closure [1,2,10]. Many studies do not distinguish between SH I/II and SH III/IV injuries producing different injury patterns of the growth plate. The results should only be applied to pure epiphyseal separations to a limited extent [6,11]. In the present prospective multicenter study, data from a total of 178 cases of physeal displacements of the lower extremity were collected; 150 of those affected the distal tibia.

This publication deals with the follow-up data, collected as part of the study up to a period of 36 months. In addition, data on weight-bearing, return-to-sports, patient satisfaction were collected and particular attention was paid to the development of post-traumatic growth disorders and their need for treatment.

Our research hypothesis was a low percentage of growth disorders according to the strict indications for reduction in primary treatment as reported prior [12].

Material and Methods

The small number of growth plate separations of the distal tibia treated each year, even in level 1 pediatric trauma centers, made a multicenter data collection essential. Eleven departments of trauma surgery and 10 departments of pediatric surgery were participating. Nine university hospitals, 8 hospitals providing specialized care and 4 hospitals providing basic care took part. The study design was developed together with the Institute for Evaluative Research in Orthopedic Surgery, University of Berne, Switzerland, and approved by the resident ethics committee. Over a period of 36 months, all subsequent patients aged 0 to 16 years, who had suffered a growth plate separation of the distal tibia, were included. Exclusion criteria were previous fractures in the area of both ankle joints, pathological fractures and fractures of other classifications (purely metaphyseal/epiphyseal fractures (SH III/IV), transitional fractures). Treatment strategy was not specified in the study protocol. Each participating clinic was asked to use its usual treatment procedure.

The follow-up period for each patient was 36 months. This period was selected, because many authors recommend a follow-up period of at least two years [3,13-15]. The total duration of the study was 6 years. The follow-up intervals after completion of the actual primary treatment were 8 weeks, 3, 6, 12, 24 and 36 months (Figure 1).

Documentation and Definitions

A documentation form was created to collect data for processing (Figure 2). Plausibility was checked by an algorithm, which was programmed for the study to avoid incorrect accidental entries.

Leg length differences were measured using the underlay method to eliminate pelvic obliquity. Varus or valgus deviations were measured clinically. Deviations were defined as the difference to the un-injured opposite side to respect inter-individual differences. Retro- and antecurvation were measured clinically, too. In cases of pathological clinical findings, plane radiographs were used for comparison. Restrictions in the range of movement were defined as deviations from the range of movement of the un-injured opposite side, estimated to be the individual normal function.

There was no study related definition which amount of Leg Length Difference (LLD) or axial deviation had to lead to an operative correction. This indication was made in an individual consideration between patient, parents and pediatric traumatologist.

Data protection

The collected data was anonymized online *via* the academic documentation portal http://www.memdoc.org and entered into a data mask with a password protection. Each patient received a consecutive number with the abbreviation of his clinic. Tracing the data and identifying the patient was only possible for the person responsible for the study at each input clinic.

Statistics

The Wilcoxon-Mann-Whitney test was used for group comparison (StatXact 8, Cytel Inc., Cambridge, MA, USA.) Power calculations for non-significant group comparisons were carried out using PASS 2008 (NCSS, LLC, Kaysville, Utah, USA). Correlations were described using the Pearson correlation coefficient. Calculations and all distribution statistics were performed using SAS 9.1 (SAS Institute Inc., Cary, NC). The α level was set at 0.05.

Results

Of the 21 participating institutions 5 contributed more than 10 cases, 8 contributed 6 to 10 cases and another 8 up to 5 cases.

Epidemiological data

Out of 178 cases 150 could be included. There were 97 (64.6%) male and 53 (35.4%) female participants. The average age was 10.9 years in girls and 12.4 years in boys (11.8 years over all). Accidents most often happened during sports (41.5%), on playgrounds (13.1%) and in traffic (10.7%). Children with traffic related injuries almost exclusively were cyclists or pedestrians. There were 18 SH I and 132 SH II injuries. 74% of the fractures were displaced, 26% were not. Physicians indicated a reduction significantly more frequently in cases with valgus deviation (p=0.0021) and antecurvation (p=0.0155) of more than 10 degrees than in cases with lesser deviation. Further data has already been published [12].

Follow up investigations

The follow-up rate was 63.3% after 8 weeks, 45.3% after one year and 27.3% after 3 years, which was the maximum follow-up interval (Figure 1).

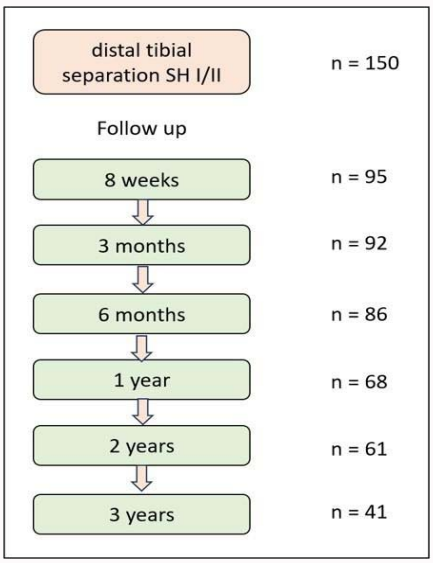

Figure 1: Number of participants at the different timepoints of follow up investigations, based on 150 primarily enclosed physeal separations of the distal tibia.

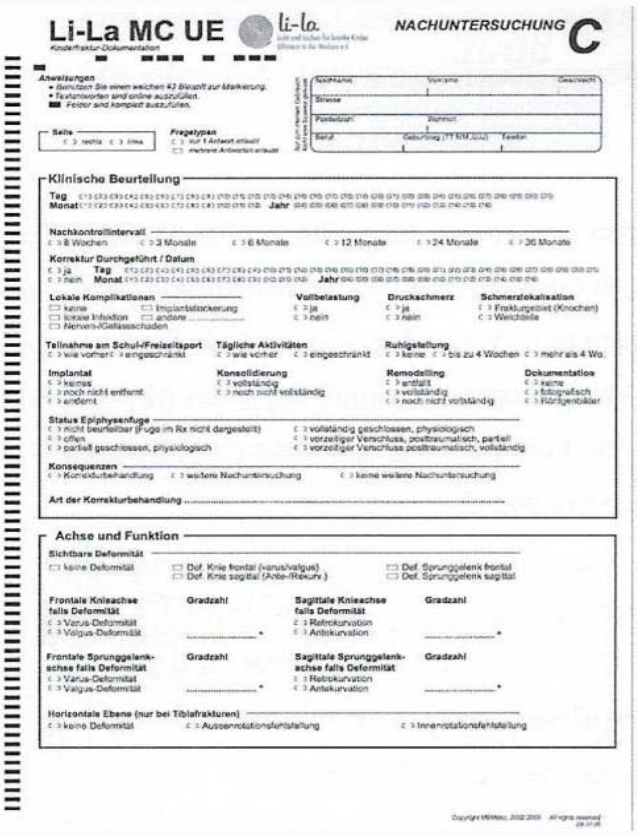
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Figure 2: Documentation form for follow up investigations [12].

Everyday activities

64.8% of the patients had already regained full weight-bearing on the injured leg at the first follow-up period. After 3 months this cumulated to 86.4%, after 6 months to 92% and after 12 months all patients were full weight-bearing. Everyday activities such as playing with friends or going to school were achieved after 8 weeks in 40% of the cases, 73.6% after 3 months and 86.4% after 6 months. According to the patient's own assessment, 42.4% had returned to their pre-injury level of sport after 3 months, 71.6% after 12 months and 85.6% after 3 years. According to their own statements, 18 children and adolescents did not return to the pre-injury level (Table 1).

Subjective assessment

85.2% of patients rated the treatment result as good or very good after 8 weeks, 95.8% after six months and 100% after one year. A single patient rated the treatment outcome as poor after 3 years at the end of the follow-up examinations.

Radiological growth plate closure

During the 6-month examination, premature partial growth plate closure of the injured tibia was noticed in two patients. After 2 years another patient experienced complete premature closure. At the end of the investigation period after 3 years, there were two further cases of partial or complete premature physeal closure. Five cases of physeal closure disorders were diagnosed after an average of 21 months. In all other patients, physiological physeal closure was either observed during the study period or had not yet occurred at the end of the study period 3 years after injury.

Clinical findings and growth disturbance

Leg length differences (LLD): LLD first appeared after 3 months in 5 patients. After 6 months LLD were present in 8 and after 12 months in 9 cases. In the further course LLD were evident in 6 cases after 2 years and in 7 cases after 3 years. At each follow-up examination there were more shortenings of the injured leg than lengthening's. The difference in leg length when the injured leg was shortened was in average 8.2 mm (5-35 mm) and when the injured leg was lengthened it was in average 6.1 mm (5-10 mm). Functional LLD with the effect of a tilted pelvis were not present in over 90%. Shortening of the affected limb was observed over the entire course of treatment in 12 children (8.0%) and lengthening in 5 children (3.3%). Statistically significant relationships between fracture specification or treatment outcome and LLD could not be demonstrated (Table 2).

Axial deviations: Axial deviations in the sagittal plane could only be detected in a few patients within first 6 months after injury. There was one case of antecurvation deformity of 5 degrees and two cases of recurvation of 5 degrees. Malalignments in the frontal plane were almost eight times more common. Valgus deformities predominated in the first year (91.3%). Two varus deviations appeared after more than one year. Statistically significant relationships between fracture specification or treatment outcome could not be demonstrated for the occurrence of axial deviations (Table 2).

Functional restrictions: Limitations in the range of motion of the affected upper ankle joint decreased from time to time of examination and were no longer detectable in any case after 3 years.

Growth disorders requiring treatment: During the follow-up examinations, four patients (2.7%) were identified, in whom the indication for corrective surgery had to be made due to a significant difference in leg length and/or a significant axial deviation. These cases are shown in Table 3.

Discussion

To our knowledge, the present study represents the largest prospectively collected series of Salter Harris I and II growth plate separations of the distal tibia in pediatric trauma literature. Many other studies do not only deal with growth plate separations but also with epiphyseal fractures (Salter Harris III and IV) [2,4,16-18].

Why differentiate SH I/II *vs.* SH III/IV injuries? Among 143 hits from a PubMed search with the search terms distal tibial growth arrest only two studies exclusively deal with Salter Harris I and II injuries [19,20-22]. However, both types of injuries have different features that make it advisable to consider them separately. Growth plate separations occur on the metaphyseal side of the growth plate, where the cartilage ossifies and merges into the metaphyseal bone [7,23]. It must be taken into consideration that growth plates are not

Table 1: Regaining activity after distal tibial physeal separations.

	Full weightbearing in every situation	full every day activity and return to sports	Full sport level recovery
8 weeks	64.80%	40%	
3 months	86.40%	73.60%	42.4%
6 months	92%	86.40%	
1 year	100%	100%	71.60%
2 years			
3 years			85.60%

Table 2: Number of functional restraints (extension/flexion) as a percentage of children examined at the respective time. Leg length differences, shortening and lengthening of the injured leg as a possible indicator of stimulating or complete inhibiting growth disturbance in absolute counts. Sagittal and frontal deviations as possible indicator of residual traumatic axial deviations or partial premature physeal closure in absolute counts. Some patients may occur with LLD and axial deviation as well (LLD: Leg Length Difference).

	Leg Length Discrepancy (LLD)	Shortening of fractured leg	Lengthening of fractured leg	Axis deviation sagittal	Axis deviation frontal	Functional restraint
8 weeks	-	-	-	-	2	21.90%
3 months	5	3	2	1	8	13.60%
6 months	8	6	2	2	4	9.30%
12 months	9	6	3	-	4	9.1%
2 years	6	4	2	-	6	7.90%
3 years	7	5	2	-	1	-

Table 3: Specifications of 4 cases with indicated operative correction of growth disturbances and premature partial or complete closure of the physeal plate.

Case	1	2	3	4
sex	male	male	male	male
age at injury	12	9	14	11
Salter-Harris	II	II	I	II
primary displacement	severe	little	severe	severe
primary treatment	closed reduction, k-wires	no manipulation, conservative	closed reduction without osteosynthesis	closed reduction, k-wires
Displacement after treatment	eliminated	-	eliminated	eliminated
Appearance of growth disturbance	24 months	12 months	12 months	36 months
Indication for corrective treatment	LLD 30 mm	LLD 20 mm, Varus 15 deg.	LLD 15 mm, Varus 15 deg.	LLD 25 mm
treatment	distraction-osteoneogenesis therapy refused	bar resection, hemi-epiphyseodesis	one stage correction of axis and length	distraction-osteoneogenesis
Time after injury	-	18 months	15 months	40 months

flat discs and that active parts of the cartilage can be injured even in case of a growth plate displacement [24]. In contrast, Salter Harris III and IV epiphyseal fractures are injuries that cross the physis. When they heal, bony bridges are formed crossing the growth plate cartilage, which may have an inhibiting effect on further growth [7,14]. In addition, these are injuries that also reach the joint surface and, if not healed, can cause permanent incongruities in the joint [25]. Furthermore, the peak age of epiphyseal fractures is lower than in physeal separations [6,7,15,26].

Return to daily activity and sports. In fractures of the ankle Camathias et al. recommend resuming weight-bearing and starting age-dependent full weight-bearing after 4 to 6 weeks [27]. Return to sports should develop gradually and slowly in order to avoid further injuries. In contrast, Del Buono et al. were unable to identify an ideal time to return to sports [28]. Accordingly, after 3 months merely half of the injured children and adolescents in our own patient group had regained their previous sport level. Porter et al. report that their patients almost reached their previous level of exercise after 2 to 4 months [29]. While 28.4% of the patients in our collective had not yet returned to their pre-accident sport level after one year, Sabatini et al. reported no more sports deficits at this point [30].

Growth disturbances. Russo et al. found growth disturbances in over 40% out of 96 SH II fractures, of which 42.5% required surgical correction [20]. Lalonde and Letts reported that 66% of the patients with post-traumatic growth disorders of the distal tibia require surgical correction [9]. In our own collective, we found a total of 19 children who were diagnosed with post-traumatic growth disorder based on leg length difference and/or valgic axial deviation upon clinical examination or in radiographic findings. This corresponds to a share of 12.7%. Likewise, Steiger et al. report on 14.6% growth disturbances in 121 Salter Harris I and II physeal separations in their study. In this collective, the correction rate was 33% [18]. Yet, no distinction was made between physeal separations and epiphyseal fractures. Seel et al. reported a similar proportion of post-traumatic growth disorders at 11.2%, but again without distinguishing between physeal separations and epiphyseal fractures [17]. In our own patient population, the rate of necessary surgical corrections was 21.1% based on the number of occurred growth disorders. This being lower than in all other studies. At 2.7% based on all injuries examined, it was also significantly lower than in the relevant textbook literature [6,7,15]. Only D'Angelo et al. reported a similarly low incidence at 2.2%; [31] Gibly et al. found a rate more than twice as high (5.3%) [5]. Both studies did not differentiate according to the types of Salter and Harris injuries.

In our opinion, the fact that the number of post-traumatic growth disorders and the number of growth disorders requiring correction is lower than in other examinations, depends on the primary treatment indications. These have already been reported prior [12]. Un-displaced fractures were treated conservatively according to the current recommendations in literature [7,13]. While participants with a valgus axial deviation of less than 10 degrees were usually not indicated for reduction, patients with a larger valgus deviation were indicated significantly ($p=0.0021$) for manual or surgical reduction. The situation was similar for post-traumatic antecurvation with a statistical significance of $p=0.0155$ [12]. Other studies used a displacement of 2 mm or more as an indication for reduction [1,18,25]. This does not do justice to the fact that most trauma related displacements are angular deformities and not pure side to side displacements measured in mm. Overall, we are convinced that in

the present patient population precise dislocation analysis and strict indication for reduction led to a low rate of growth disorders, especially those requiring surgical revision. Cottalorda et al. came to a similar result for a retrospectively analyzed group of Salter Harris III and IV fractures of the distal tibia [9]. In contrast to other investigators, they did not observe any relevant growth disorders. They reasoned with a strict indication for reduction and osteosynthesis already at a dislocation of one mm, instead of at a dislocation of 2 mm or more as in most other studies.

Due to the small amount of surgically relevant growth disorders, we were not able to identify risk factors for their development as they were stated by other authors [2,9,10]. We can only conclude that strictly indicating axial deviations above 10 degrees for reduction, achieves our very low rate of relevant growth disturbances.

Corrective techniques: The surgical methods chosen to correct post-traumatic growth disorders in our series can also be found in the literature. While Gibly et al. mostly used epiphyseodesis of the opposite side to equalize leg length, distraction osteoneogenesis was chosen more often in our cases [5]. Axial correction was carried out once using a hemiepiphysiodesis in a very young patient and once using a single stage corrective osteotomy in a patient with insufficient residual growth. For the simultaneous treatment of length differences and axial deviations, Monsell et al. report on the use of the Taylor Spatial Frame, which is certainly a good but sophisticated alternative [32]. Lalonde and Letts used bar resections and epiphyseodesis for correction [9]. Overall, the indication for the surgical revision must be made individually, taking the extent of the deformity and difference in leg length into consideration. Above all the expected residual growth should be contemplated [6,7].

Limitations: A weakness of the study is certainly the significant loss of participants within the 36-month observation period. Some injured children also missed individual follow-up appointments but took part again later. Those responsible for the study in the respective clinics reported that in many cases of normal and satisfactory outcomes, it was hardly possible to motivate the patients and their parents to attend the longer-term follow-up appointments. Conversely, it can be assumed that patients with remaining disorders and secondary limitations due to the development of a growth disorder could be fully recorded. Another limitation may be the different level of participation in the pediatric trauma centers.

Conclusion

Most children and adolescents with a growth plate separation of the distal tibia achieve a good result. However, not everyone returns to his or her previous level of sport. In our collective inhibiting post-traumatic growth disorders were less common than in most of the previous studies. We attribute this to the fact, that primary displacements of more than 10 degrees of antecurvation or valgus were primarily corrected by the participating pediatric traumatologists. We recommend reducing physeal separations of the distal tibia within these very narrow limits to avoid growth disorders as far as possible. The remaining cases of post-traumatic growth disorders must be understood as faithful and related to primary bone damage. They manifest themselves as increasing leg length differences and/or increasing varicose ankle joint axis. Small differences in leg length, especially without axial deviations, can be treated conservatively. The indication for corrective surgery must be made individually and, above all, the expected residual growth should be taken into consideration. Methods available include growth guidance, bar resection, ad hoc correction and distraction osteoneogenesis.

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