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ORIGINAL STUDY

Leg length discrepancy following femoral shaft fracture in children : Clinical considerations and recommendations

Hélène Hariga, Maryline Mousny, Pierre-Louis Docquier

From the Cliniques Universitaires Saint-Luc, Brussels, Belgium

Femoral shaft fracture in children is a frequently encountered problem. Residual leg length discrepancy persisting at skeletal maturity is the most common complication. In this study, a positive correlation was found between the amount of bone fragments overlap and the overgrowth phenomenon. When comparing final leg-length discrepancy with initial fragments overlap, 9.3 mm was found to be the maximal overlap to be tolerated in order to avoid significant leg length discrepancy.

Keywords : femoral shaft fracture ; children ; leg length discrepancy.

INTRODUCTION

The femoral shaft is the third most common location of fractures in children, after those of the upper limbs. Prognosis is usually good due to the high bone remodeling potential in children. Non-operative treatment is the gold standard for children less than 6 years of age because of the strong potential for bone union and remodeling. However, the main complication of femoral shaft fractures is a possible leg length discrepancy (LLD), resulting from the initial overriding of the bone fragments and/or from the overgrowth phenomenon in the fractured limb.

The mean overgrowth of the fractured femur has been shown to be 7 to 8 mm by Reynolds *et al* (7), 8.1 mm by Clement and Colton (2), 9.2 mm by Shapiro (9), 10 mm by Edvardsen and Syversen (3), 10.8 mm by Hougaard (4) and 11.7 mm by Nordin *et al* (6). Most of the overgrowth (78%) has been shown to occur within the first 18 months following the fracture (6,7,9).

To avoid any LLD due to this subsequent overgrowth, it could be appropriate to tolerate an overriding of the bone fragments before union so that the consecutive overgrowth would compensate for the initial shortening.

Various authors have recommended different amounts of overlap : Stephens *et al* (10) less than 10 mm, Shapiro (9) and Reynolds *et al* (7) 15 mm, Edvarsen and Syversen (3) 15 to 20 mm and Barfod and Christensen (1) 20 mm. This wide range could be explained by differences in the methods used to assess limb length and by differences in the mean

■ Hélène Hariga, MD, Resident.
■ Maryline Mousny, MD, PhD, Orthopaedic Surgeon.
■ Pierre-Louis Docquier, MD, PhD, Orthopaedic Surgeon.
Department of Orthopaedic Surgery, Cliniques universitaires St-Luc, Bruxelles, Belgium.
Correspondence : Pierre-Louis Docquier, Department of Orthopaedic Surgery, Cliniques Universitaires Saint-Luc, 10, avenue Hippocrate, B-1200 Bruxelles, Belgique.
E-mail : Pierre-Louis.Docquier@uclouvain.be

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time of follow-up. Only Shapiro (9) and Stephens *et al* (10) have reported radiological measurements at skeletal maturity.

The purpose of this study was to assess the final LLD in children treated in our department for an isolated femoral shaft fracture and to determine guidelines to minimize it.

MATERIALS AND METHODS

Patients

The charts of 37 children treated for an isolated femoral shaft fracture between September 1958 and July 2010 were retrospectively reviewed and the radiological results were analyzed. The clinical data of the 37 patients are summarized in Table I. There were 27 boys and 10 girls with a mean age of 4 years and 2 months (range : 9 months to 10 years and 8 months). There were 16 right-sided and 21 left-sided femoral fractures.

Thirty one children were treated conservatively with initial skin traction for a mean period of 14.6 days followed by a spica cast for a mean period of 28.7 days. Six patients were treated surgically by elastic stable intramedullary nailing (ESIN).

The mean follow-up was 4 years and 10 months. At latest follow-up, the mean age was 9 years and five patients had reached skeletal maturity (14%).

Radiographic evaluation

Anteroposterior (AP) and lateral femur radiographs at the time of fracture were analyzed to assess the side (left, right), the level (proximal, middle or distal third), the type (transverse, oblique,spiral) of each fracture. AP and lateral femur radiographs performed 6 weeks after injury were analyzed to measure the amount of bone ends overlap (in mm) (Fig. 1), and angulation in frontal and in sagittal plane (in degrees) (Fig. 2). Bone ends overlap was measured on an AP radiograph. In some difficult cases due to the callus, overlap was measured on the lateral radiograph. A negative value in discrepancy indicates a shortening, a negative angle in the coronal plane indicates a valgus deformity and in the sagittal plane a recurvatum.

We considered a radiological magnification of 10% for femoral radiographs based on a literature review (5). We also experimentally confirmed this 10% magnification by obtaining a radiograph of a graduated ruler in the same conditions as for a child femoral radiograph.

Table I. — Clinical data of the 37 patients

Patients (N)	37
Sex Ratio (M/F)	27/10 = 2.7
Mean age at the time of fracture (yrs)	4.2 (0.8 to 10.7) yrs
Fracture side (left/right)	21/16
Fracture level : – proximal third – mid-shaft – distal	 16.2% of patients 75.7% 8.1%
Fracture type : – transverse – oblique – spiral	 24.3% of patients 13.5% 62.2%
Treatment type – surgical (ESIN) – conservative (traction followed by spica cast) – mean time in traction (days) – mean time in spica cast (days)	 6 patients 31 patients 14.6 (0 to 42) 28.7 (0 to 78)

ESIN = Elastic stable intramedullary nailing.

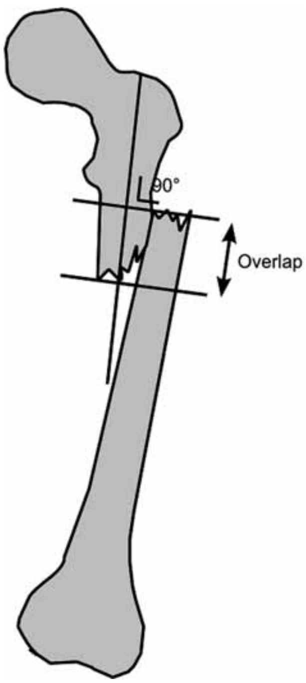

Fig. 1. — Measurement method for overlap. The long axis of the proximal diaphysis is the reference. A first line perpendicular to this axis is drawn through a point at the distal end of the proximal fragment. A second line parallel to this first line is drawn through a point at the proximal end of the distal fragment. The shortening of the femur is the distance between the two lines drawn previously. A negative value is given to shortening and a positive value to lengthening.

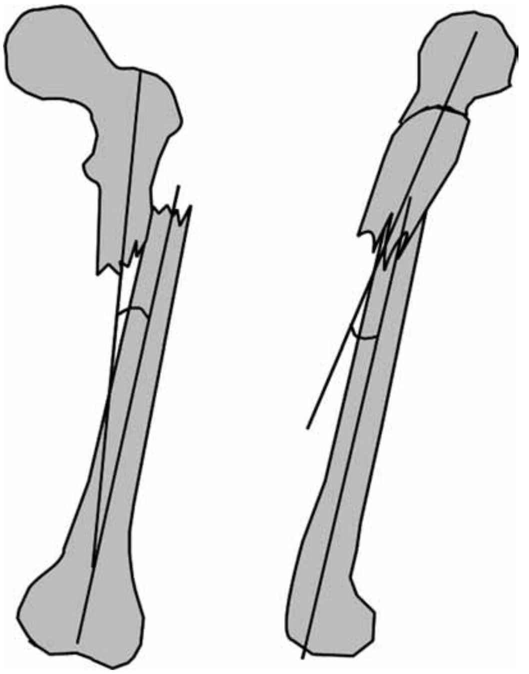

Fig. 2. — Angle measurement method in the coronal and sagittal plane. The long axes of the proximal and distal diaphysis intersect, giving an angle. A negative value in the coronal plane indicates a valgus. A negative value in the sagittal plane indicates a recurvatum.

Radiographic measurement of leg length discrepancy (LLD)

We used teleroentgenograms (full-length standing AP radiograph) for the measurement of LLD (8). A single long cassette was placed behind the standing patient. A single radiograph of both lower limbs was performed, with the x-ray beam centered on the knee at a minimum distance of 3.5 m while the patient was standing with both patellae pointing anteriorly. An attempt was made to level the pelvis with an appropriately sized lift placed under the shorter limb. For these radiographs, we considered no magnification based on a review (8) and on an experiment (we made a teleroentgenogram with a graduated ruler and we did not find any magnification).

Femoral length was measured from the top of the femoral head to the distal end of the medial femoral condyle. Tibial length was measured from the bottom of the medial tibial condyle to the center of the distal tibial epiphysis. The femorotibial limb length was measured from the top of the femoral head to the center of the distal tibial epiphysis. The LLD was also measured at the level of the femoral heads (we compared the difference between the heights of the tops of the two femoral heads, which was recorded in mm).

The femoral overgrowth (in mm) was measured as the initial overlap value minus the final femoral length discrepancy. The tibial overgrowth was the final tibial length discrepancy.

Statistical analysis

PAWS 18 (Predictive Analytics SoftWare, 2009, IBM, USA) was used. A significance level of $p < 0.05$ was used. The non-parametric Mann-Withney test was used to compare the numerical data. For the categorical data, a non-parametric Fisher's exact test was performed.

RESULTS

Table II summarizes the radiological findings of the 37 patients. At the latest follow-up, the fractured

Table II. — Radiological findings in the 37 patients. A negative value indicates a shortening of the fractured femur or limb

	Mean (mm)	Minimum (mm)	Maximum (mm)	Standard deviation
Follow-up (yrs)	4.9	0.5	17.7	4.6
Age at latest follow-up	9.1	2.2	22.8	5.4
Measurements at 6 weeks				
Overlap (mm)	-11.8	-39	1	9.6
Coronal angulation (°)	6.1	-10	29	10
Sagittal angulation (°)	5.6	-3	36	8.1
Measurements at last follow-up				
Femoral length discrepancy (mm)	-2.1	-17	21	9.1
Tibial length discrepancy (mm)	0.6	-7	8	2.8
Femoro-tibial length discrepancy (mm)	-1.5	-22	22	10.5
Leg length discrepancy measured at femoral heads (mm)	-3.5	-18	14	6.7
Overgrowth (mm)	9.7	8	30	8.3

limb was shorter than the normal limb : 1.5 mm on average based on measurements of the femorotibial skeleton and 3.5 mm on average based on the level of the femoral heads on the patient in the standing position. The major part of this shortening was due to the fractured femur (2.1 mm shortening on average). The ipsilateral tibia showed a slight compensation, as it was 0.6 mm longer on average. The mean femoral overgrowth was 9.6 mm and the mean tibial overgrowth was 0.6 mm.

DISCUSSION

Our series, although small, is comparable to other larger series (*2,3,4,6,7,9,10*). Male children were predominant. The two sides were nearly equally affected, despite a slight left predominance. The middle third of the femur was the most affected (60-78%) followed by the proximal third and the distal third respectively.

Overgrowth and factors influencing overgrowth

In our series the femoral overgrowth averaged 9.6 mm which is comparable to other studies (*2,3,4,6,7,9*). We observed overgrowth in 86% of the children, unlike Shapiro (*9*) who found it in 100%.

Femoral overgrowth was significantly influenced by the initial overlap ($p = 0.02$). The more important the overlap, the more significant was the overgrowth (Fig. 3). This effect of overlap had already been shown by Edvardsen and Syversen (*3*), and by Reynolds (*7*). On the contrary, other factors such as age ($p = 0.239$), sex ($p = 0.189$), fracture level ($p = 0.893$), fracture type ($p = 0.938$) and treatment type ($p = 0.749$) did not statistically influence overgrowth. These results are in agreement with the findings of other authors (*3,4,6,7,9*), except for Clement and Colton (*2*) who found an influence of gender on overgrowth, for Barfod and Cristensen (*1*) who found an influence of the fracture level and for Edvardsen and Syversen (*3*) who found an influence of the fracture type. The angulation in the frontal and sagittal planes did not influence the overgrowth.

Shapiro noted a 2.9 mm overgrowth of the ipsilateral tibia in 82% of patients (*9*) while we found a 0.6 mm tibial overgrowth.

Factors influencing final leg length discrepancy

The final LLD was significantly influenced by the initial overlap ($p = 0.0003$).The equation for regression analysis was : Final LLD = 5.8 mm-(0.62 × initial overlap). According to this equation, 9.35 mm would be the optimal overlap that would lead to a minimal LLD (Fig. 4). On the contrary, the final LLD was not influenced by overgrowth ($p = 0.244$), by sex ($p = 0.093$), by age at the time of

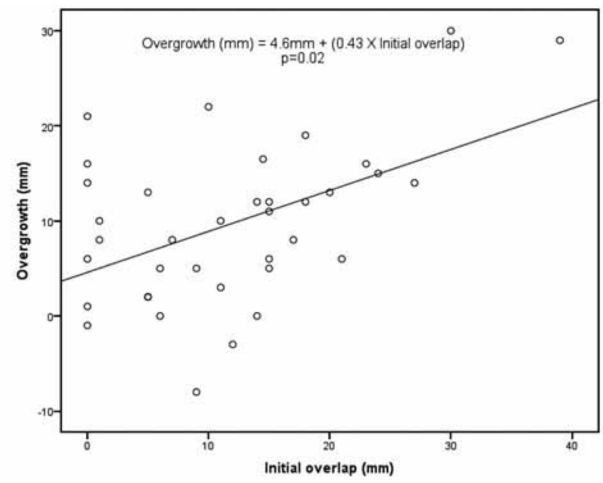

Fig. 3. — Graph showing the regression curve between overgrowth and initial overlap (r = 0.485, p = 0.02).

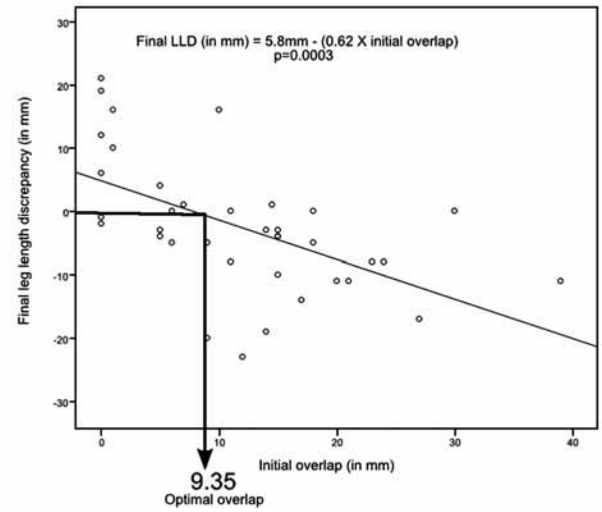

Fig. 4. — Graph showing the regression curve between final LLD and initial overlap (r = 0.559, p = 0.0003).

trauma (p = 0.071), by fracture type (p = 0.926), by fracture level (p = 0.132) nor by treatment type (p = 0.106).

Frontal angulation (p = 0.532) or sagittal angulation (p = 0.227) did not influence the final LLD. Our results do not agree with Hougaard (*4*) and Stephens *et al* (*10*) who found a relationship between initial angulation and final LLD (*4*).

Considering that most of the overgrowth (78%) occurs in the first 18 months after fracture (*6,7,9*), that the overgrowth phenomenon stops after 3 years and 6 months (*9*) in the vast majority of patients (85%), and that LLD remains unchanged until the end of growth, we can conclude that LLD measured on averagef 4.9 years after fracture is a good representation of the final LLD at skeletal maturity.

Factors influencing overlap

The type of treatment significantly influenced the overlap at union. With surgical treatment (ESIN) the overlap was significantly less (p = 0.024). This can be explained by the better reduction obtained in case of surgical treatment, minimizing the shortening. In cases of conservative treatment, no correlation was found between overlap at the time of union and the duration of skin traction (p = 0.624).

Table III. — Comparison of conservative and surgical treatment

	Nonoperative treatment	Surgical Treatment (ESIN)	p value
Patients (N)	31	6	
Mean overlap at time of union (in mm)	13.3	4.0	p = 0.024
Mean overgrowth (in mm)	9.9	8.8	p = 0.106
Final femorotibial discrepancy (in mm)	-2.7	4.8	p = 0.788

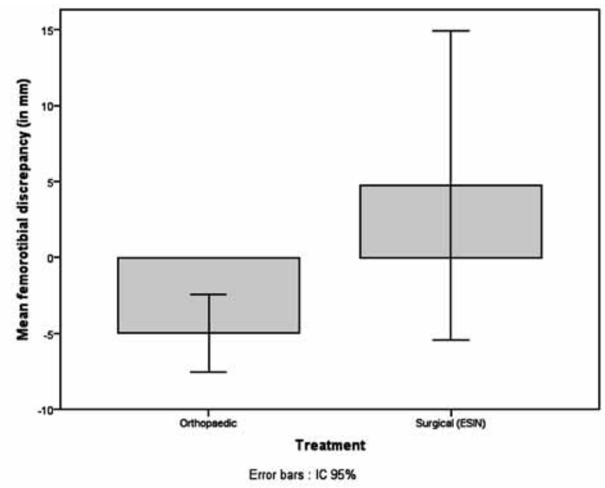

Fig. 5. — Graph showing the measured final LLD for both treatment types.

Influence of the type of treatment

Although the type of treatment significantly influenced the overlap at union, it did not significantly influence overgrowth nor LLD (Table III). With surgical treatment the fractured limb was 4.8 mm longer on average, while it was 2.7 mm shorter with the nonoperative treatment (Fig. 5). This difference was not statistically significant probably due to the small size of the cohort treated with ESIN.

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