Leg-length discrepancy and associated risk factors after paediatric femur shaft fracture: a multicentre study

Tae Gyun Kim[1]
Moon Seok Park[2,3]
Sang Hyeong Lee[4]
Kug Jin Choi[2]
Byeong-eun Im[2]
Dae Yeung Kim[1]
Ki Hyuk Sung[2,3]

Abstract

Purpose: This study was performed to investigate leg-length discrepancy (LLD) and associated risk factors after paediatric femur shaft fractures.

Methods: A total of 72 consecutive patients under 13 years old (mean age 6.7 years; 48 boys, 24 girls) with unilateral femur shaft fracture, and a minimum follow-up of 18 months, were included. The amount of LLD was calculated by subtracting the length of the uninjured from that of the injured limb. Risk factors for an LLD ≥ 1 cm and ≥ 2 cm were analyzed using multivariable logistic regression analysis.

Results: Hip spica casting, titanium elastic nailing and plating were performed on 22, 40 and ten patients, respectively. The mean LLD was 7.8 mm (sd 8.8) and 29 (40.3%) had a LLD of ≥ 1 cm, while nine (12.5%) had a LLD of ≥ 2 cm. There were significant differences in fracture stability (p = 0.005) and treatment methods (p = 0.011) between patients with LLD < 1 cm and ≥ 1 cm. There were significant differences in fracture site shortening (p < 0.001) and LLD (p < 0.001) between patients with length-stable and length-unstable fractures. Fracture stability was the only factor associated with LLD ≥ 1 cm (odds ratio of 4.0; p = 0.020) in the multivariable analysis.

Conclusion: This study demonstrated that fracture stability was significantly associated with LLD after paediatric femur shaft fractures. Therefore, the surgeon should consider the possibility of LLD after length-stable femur shaft fracture in children.

Level of Evidence: Prognostic level III

[1] Department of Orthopaedic Surgery, Konyang University Hospital, Daejeon, Korea
[2] Department of Orthopaedic Surgery, Seoul National University Bundang Hospital, Gyeonggi, Korea
[3] Department of Orthopaedic Surgery, Seoul National University College of Medicine, Seoul, Korea
[4] Department of Orthopaedic Surgery, Dongguk University Ilsan Hospital, Gyeonggi, Korea

Correspondence should be sent to: Ki Kyuk Sung, Department of Orthopaedic Surgery, Seoul National University Bundang Hospital, 82 Gumi-ro 173 Beon-gil, Bundang-Gu, Sungnam, Gyeonggi 13620, Korea.
E-mail: skh1219@naver.com

Introduction

Femoral shaft fractures represent about 1.6% of all paediatric fractures, and occur in a bimodal distribution with peaks during the toddler and early adolescence stages.[1] Treatment methods for paediatric femoral shaft fractures include Pavlik harness, immediate or delayed hip spica casting, external fixation, flexible or rigid intramedullary nailing and plate fixation. The method depends on the patient's age, weight, fracture pattern and the surgeon's preference.[2-11]

The most common sequela after a paediatric femoral shaft fracture is leg-length discrepancy (LLD) owing to overgrowth of the injured femur. Many studies have investigated the biomechanical effects of LLD, and reported low back pain, hip pain and stress fractures to be musculoskeletal disorders associated with LLD.[12-14] Most of the overgrowth has been shown to occur within the first 18 months following the fracture.[15-17] It is believed that this is due to a physiological process associated with post-traumatic activation of the growth plate.[18] The mean overgrowth is approximately 1 cm and thus a proper amount of bayonet apposition is required for hip spica casting in young children.

Several studies have investigated the factors affecting overgrowth after paediatric femoral shaft fracture.[16,17,19-23]

Age, fracture site, fracture stability, degree of overlap and nail-canal diameter (NCD) ratio have been suggested as risk factors for femoral overgrowth. However, there are a lack of studies analyzing the risk factors for LLD after a paediatric femoral shaft fracture. Therefore, we performed this study to investigate the LLD after a paediatric femur shaft fracture and its associated risk factors.

Materials and methods

This retrospective study was approved by the institutional review board of our hospital. Informed consent was waived due to the retrospective design of this study.

Study population and data collection

Consecutive patients with a unilateral femur shaft fracture who were < 13 years old and had a minimum follow-up of 18 months at three institutions were included in this study. The exclusion criteria were as follows: 1) bilateral femur shaft fracture; 2) ipsilateral or contralateral lower limb fractures; or 3) pathological fracture due to cerebral palsy, bone tumour or osteogenesis imperfecta.

From the medical record review, the following information was obtained: sex, age, height, weight, body mass index (BMI), follow-up duration, side of limb, range of movement of the hip and knee joints, injury mechanism and treatment method. Injury mechanisms were divided into high-energy and low-energy injuries. We defined traffic accidents, sports injury and a fall from a height as high energy injuries, and slipping and falling from ground-level as low energy injuries. All fractures were treated by four paediatric orthopedic surgeons (MSP, SHL, KHS and TGK). Treatment methods included hip spica casting, titanium elastic nailing (TEN) and plating.

Radiographic measurements

From the preoperative anteroposterior (AP) and lateral radiographs of the injured femur, fracture location and fracture stability were determined. Fracture locations were classified as proximal third, middle third and distal third. Fractures were divided into length-stable and length-unstable fractures according to fracture stability. Transverse and short oblique fractures were classified as length-stable fractures; and long oblique, spiral, and comminuted fractures were classified as length-unstable fractures. Long oblique fractures were defined when the angle between the fracture line and a line perpendicular to the long axis of the femur was > 30°. Fracture-site shortening was measured from the postoperative AP and lateral radiographs of the femur.

To assess the limb length, the AP standing long-cassette radiographs of the lower extremity (teleroradiogram) were taken using a UT 2000 x-ray machine (Philips Research, Eindhoven, The Netherlands) at a source-to-image distance of 200 cm, and set at 50 kVp and 5 mAs with the patella facing forward. It consisted of a single radiographic exposure of both lower limbs, with the x-ray beam centred at the knee. Until two years after the trauma, a teleradiogram was taken regularly once per year. Thereafter, if the LLD was ≥ 1 cm, a teleradiogram was recommended to be regularly performed once every one to two years. Otherwise, a regular examination was decided according to the parents' need. The radiographic images were retrieved using a picture archiving and communication system (PACS) (IMPAX; Agfa Healthcare, Mortsel, Belgium), and radiographic measurements were performed using PACS software. The whole limb length (WLL) was measured from the teleroentgenograms of the final follow-up. The WLL was defined as the length from the top of the femoral head to the center of the tibial plafond (Fig. 1).

Before the main measurement, inter-observer reliability testing was performed for the WLL measurements. Two orthopaedic surgeons (KJC and BI) with six and four years of experience, respectively, independently measured the WLLs for 15 radiographs. After reliability testing, one of the authors (BI) measured all radiographic measurements.

The amount of LLD was calculated by subtracting the uninjured limb length from the injured limb length. Overgrowth was calculated by adding the fracture site shortening to the LLD. In order to investigate the risk factors for LLD, patients were divided into those with a LLD of < 1 cm or ≥ 1 cm according to Flynn's criteria[24] and those with an LLD of < 2 cm or ≥ 2 cm.

Statistical analysis

Reliability was assessed by the intraclass correlation coefficient (ICC) and 95% confidence interval (CI) in the setting of a two-way random-effect model, assuming a single measurement and absolute agreement.[25] With a target ICC value of 0.9 and 95% CI width of 0.2 for two observers, the minimal sample size was determined to be 15 radiographs using Bonett's methods.[26]

To summarize patient demographics, descriptive statistics such as mean and sd were used. The chi-squared test or Fisher's exact test, and independent *t*-test or Mann-Whitney U test were used for comparisons of variables between groups. Multivariable logistic regression analysis was used to identify the risk factors for LLD after a paediatric femur shaft fracture after univariable analysis. Variables with a p-value < 0.1 in the univariable analysis were included in the multivariable analysis. All statistical analyses were conducted with SPSS software for Windows (Version 25.0; SPSS Inc, Chicago, Illinois). All statistics were two-tailed and p-values of < 0.05 were considered statistically significant.
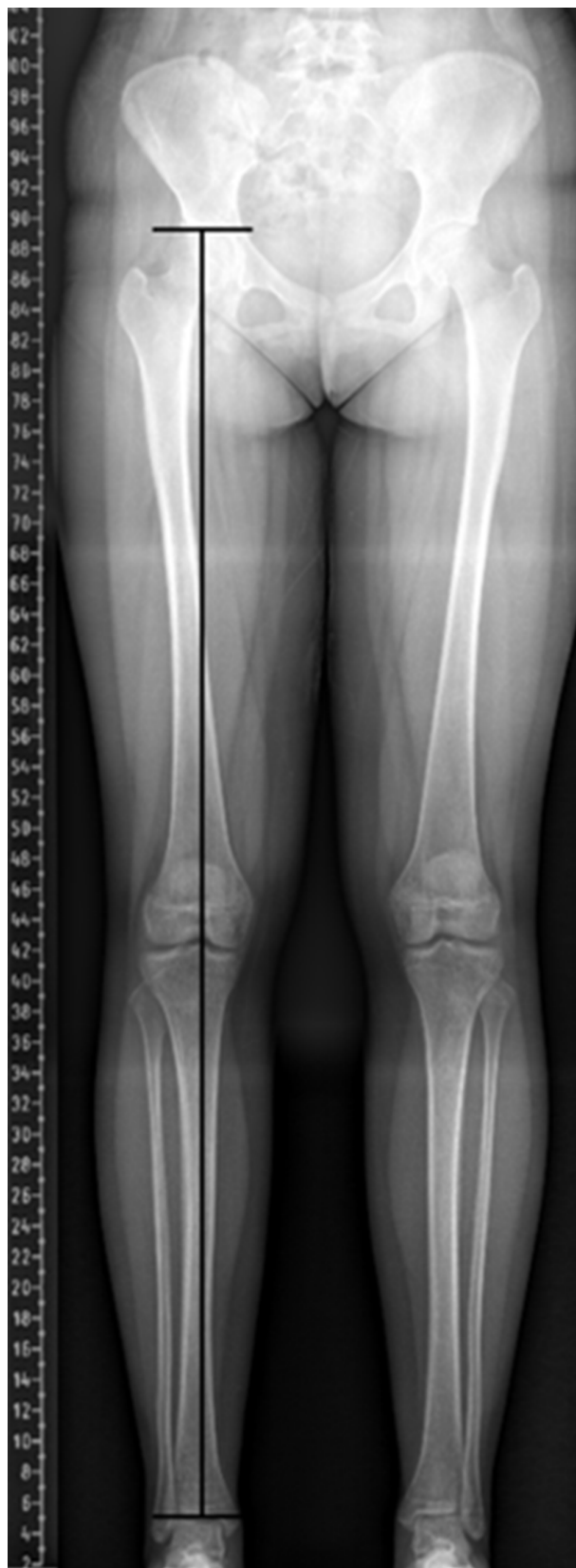
Fig. 1 Whole limb length was defined as the length from the top of the femoral head to the center of the tibial plafond.

Results

In total, 98 patients with a femur shaft fracture who were < 13 years old were screened. After implementation of the exclusion criteria, a total of 72 patients remained in this study of which 48 were boys and 24 were girls (Fig. 2). The mean age of the patients at the time of injury was 6.7 years (sd 2.9). There were 43 length-stable and 29 length-unstable fractures. The mean follow-up duration was 3.8 years (sd 2.7). Hip spica casting was performed on 22 patients, TEN on 40 patients and plating on ten patients. Mean LLD and mean overgrowth were 7.8 mm (sd 8.8; 95% CI 5.7 to 9.8) and 12.0 mm (sd 8.2; 95% CI 10.2 to 14.0), respectively. Of the 72 patients, 29 (40.3%) had a LLD of ≥ 1 cm and nine (12.5%) had a LLD of ≥ 2 cm (Table 1). Of these nine patients, four underwent additional surgeries for the correction of LLD at a mean interval of 3.5 years after initial surgery. Three boys underwent epiphysiodesis of the distal femur at the ages of 12.8, 13.0 and 10.3 years, respectively, and one girl underwent femoral lengthening of contralateral side using an Ilizarov external fixator at the age of 12.2 years. None of the patients had flexion contracture of the hip or knee joints.

Radiographic measurements for WLL showed excellent interobserver reliability (ICC 0.958; 95% CI 0.886 to 0.983).

There were significant differences in fracture stability (p = 0.005) and treatment methods (p = 0.011) between patients with LLDs < 1 cm and ≥ 1 cm. However, there were no significant differences in sex, age, BMI, fracture location, follow-up duration and injury mechanism between the two groups. There were no significant differences in any variable between patient with LLDs < 2 cm and ≥ 2 cm (Table 2).

There were significant differences in fracture site shortening (p < 0.001), and LLD (p < 0.001) between patients with length-stable and those with length-unstable fractures. However, there were no significant differences in sex, age, BMI, fracture location, injury mechanism, follow-up duration, treatment methods and overgrowth between the two groups (Table 3).

Patients treated with hip spica cast showed a younger age and a greater degree of fracture site shortening than those treated with TEN and plating (all p < 0.001). LLD in patients treated with hip spica cast (4.2 mm) was smaller than that in those treated with TEN (9.2 mm) and plating (10.5 mm), but the difference was not statistically significant (p = 0.055). The degree of overgrowth did not differ according to treatment modality (Table 4).

After univariable analysis, age, fracture stability, follow-up duration and treatment methods were included in a multivariable logistic regression analysis. Fracture stability was the only factor that was found to be associated
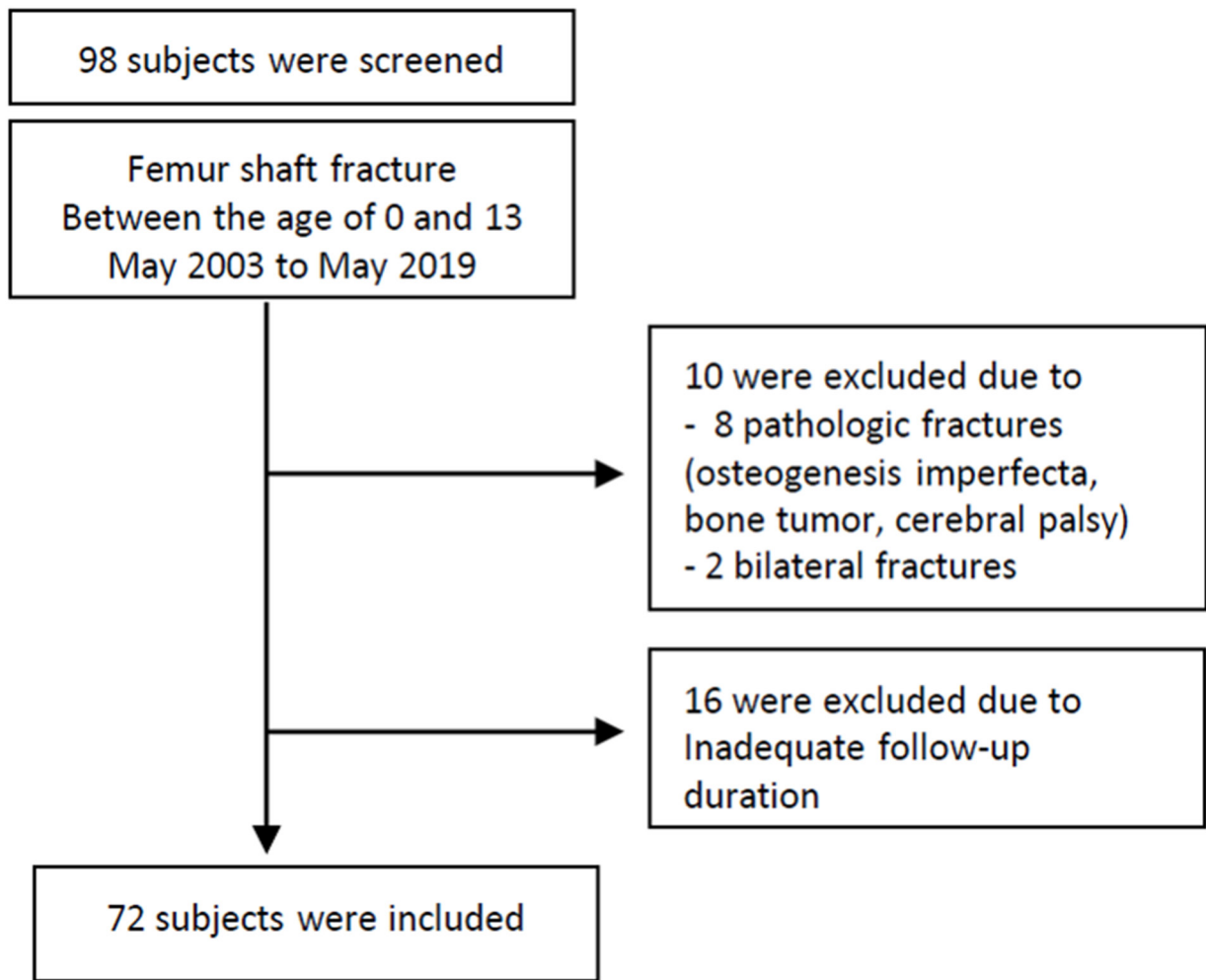
```
┌─────────────────────────────────┐
│  98 subjects were screened      │
└─────────────────────────────────┘

┌─────────────────────────────────┐
│  Femur shaft fracture           │
│  Between the age of 0 and 13    │──────────────┐
│  May 2003 to May 2019           │              │
└─────────────────────────────────┘              ▼
        │                          ┌───────────────────────────────┐
        │                          │ 10 were excluded due to       │
        │                          │ -  8 pathologic fractures     │
        │                          │ (osteogenesis imperfecta,     │
        │                          │ bone tumor, cerebral palsy)   │
        │                          │ - 2 bilateral fractures       │
        │                          └───────────────────────────────┘
        │
        │                          ┌───────────────────────────────┐
        │──────────────────────────▶ 16 were excluded due to       │
        │                          │ Inadequate follow-up          │
        │                          │ duration                      │
        ▼                          └───────────────────────────────┘
┌─────────────────────────────────┐
│  72 subjects were included      │
└─────────────────────────────────┘
```

Fig. 2 Inclusion and exclusion criteria.

Table 1 Summary of patient demographics

Demographic	Patients
Sex, male/female	48/24
Mean age, yrs (SD; range)	6.7 (2.9; 1.3 to 12.9)
Mean height, m (SD)	1.22 (0.20)
Mean weight, kg (SD)	26.2 (11.9)
Mean body mass index, kg/m^2 (SD)	17.6 (3.8)
Side of limbs, right/left	39/33
Fracture location, proximal third/middle third/distal third	20/49/3
Stability, length-stable/length-unstable	43/29
Injury mechanism, high energy/low energy	49/23
Mean follow-up duration, yrs (SD)	3.8 (2.7)
Treatment, hip spica cast/TEN/plating	22/40/10
Mean fracture site shortening, mm (SD)	3.9 (4.9)
LLD ≥ 1 cm, yes/no	29/43
LLD ≥ 2cm, yes/no	9/63
Mean LLD, mm (SD)	7.8 (8.8)
Mean overgrowth, mm (SD)	12.0 (8.2)

TEN, titanium elastic nailing; LLD, leg-length discrepancy

with an LLD of ≥ 1 cm after paediatric femur shaft fracture (p = 0.020). Patients with length-stable fractures had 4.0 times higher risk of LLD ≥ 1 cm (Table 5). However, no significant risk factors were found to be associated with LLD ≥ 2 cm in the multivariable logistic regression analysis (Table 6).

Table 2 Comparison of variables between patients with LLD < 1 cm and ≥ 1 cm, and patients with LLD < 2 cm and ≥ 2 cm

	LLD < 1 cm, n = 43	LLD ≥ 1 cm, n = 29	p-value*	LLD < 2 cm, n = 63	LLD ≥ 2 cm, n = 9	p-value*
Sex, male/female	27/16	21/8	0.396	41/22	7/2	0.708
Mean age, yrs (SD)	6.2 (3.2)	7.5 (2.2)	0.064	6.7 (3.0)	7.0 (2.4)	0.710
Body mass index (kg/m^2)	17.6 ± 4.2	17.7 ± 3.2	0.888	17.8 ± 4.0	16.9 ± 2.1	0.818
Fracture location, proximal third/middle third/distal third	11/30/2	9/19/1	0.864	15/45/3	5/4/0	0.176
Stability, length-stable/length-unstable	20/23	23/6	0.005	35/28	8/1	0.056
Injury mechanism, high energy/low energy	26/17	23/6	0.093	43/20	6/3	1.0
Mean follow-up duration, yrs (SD)	3.3 (2.4)	4.5 (2.9)	0.051	3.6 (2.6)	5.0 (3.0)	0.149
Treatment, cast/internal fixation	18/25	4/25	0.011	20/43	2/7	0.713
Mean fracture site shortening, mm (SD)	4.7 (5.2)	2.6 (4.4)	0.084	3.9 (4.8)	3.8 (5.9)	0.667

LLD, leg-length discrepancy
*p-value based on chi-squared test or Fisher's exact test (categorical variables), and independent *t*-test or Mann-Whitney U test (continuous variables)

Table 3 Comparison of variables between length-stable and length-unstable fractures

	Length-stable fracture, n = 43	Length-unstable fracture, n = 29	p-value*
Sex, male/female	26/17	22/7	0.174
Mean age, yrs (SD)	6.7 (3.0)	6.7 (2.8)	0.958
Body mass index (kg/m^2)	18.1 (4.0)	16.9 (3.4)	0.241
Fracture location, proximal third/middle third/distal third	12/30/1	8/19/2	0.633
Injury mechanism, high energy/low energy	33/10	16/13	0.054
Mean follow-up duration, yrs (SD)	4.1 (2.8)	3.2 (2.4)	0.171
Treatment, hip spica cast/internal fixation	11/32	11/18	0.265
Mean fracture site shortening, mm (SD)	2.0 (3.9)	6.6 (5.1)	< 0.001
LLD ≥ 1 cm, yes/no	23/20	6/23	0.005
LLD ≥ 2 cm, yes/no	8/35	1/28	0.056
Mean overgrowth (SD)	13.2 (8.9)	10.3 (6.8)	0.137
Mean LLD (SD)	10.6 (8.5)	3.6 (7.4)	0.001

LLD, leg-length discrepancy
*p-value based on chi-squared test or Fisher's exact test (categorical variables), and independent *t*-test or Mann-Whitney U test (continuous variables)

Table 4 Comparison of variables between patients who underwent hip spica cast, titanium elastic nailing (TEN) and plating

	Hip spica cast, n = 22	TEN, n = 40	Plating, n = 10	p-value*
Sex, male/female	14/8	27/13	7/3	0.926
Mean age, yrs (SD)	4.1 (2.3)	7.7 (2.5)	8.3 (1.3)	< 0.001
Body mass index (kg/m^2)	16.2 (1.9)	18.2 (4.4)	17.7 (2.8)	0.239
Fracture location, proximal third/middle third/distal third	3/18/1	11/27/2	6/4/0	0.108
Stability, length-stable/length-unstable	11/11	26/14	6/4	0.515
Injury mechanism, high energy/low energy	9/13	32/8	8/2	0.005
Mean follow-up duration, yrs (SD)	3.8 (3.2)	3.7 (2.4)	3.8 (2.8)	0.993
Mean fracture site shortening, mm (SD)	8.2 (5.3)	2.1 (3.3)	1.4 (3.4)	< 0.001
LLD ≥ 1 cm, yes/no	4/18	21/19	4/6	0.031
LLD ≥ 2 cm, yes/no	2/20	5/35	2/8	0.688
Mean overgrowth (SD)	11.9 (8.2)	12.1 (8.3)	12.0 (8.7)	0.994
Mean LLD (SD)	4.2 (8.2)	9.2 (8.3)	10.5 (9.9)	0.055

LLD, leg-length discrepancy
*p-value based on chi-squared test or Fisher's exact test (categorical variables), and analysis of variance (continuous variables)

Discussion

LLD due to femoral overgrowth following a femur shaft fracture in children is a well-known phenomenon. If the LLD exceeds or is expected to exceed 2 cm to 2.5 cm at skeletal maturity, length equalization procedures, such as epiphysiodesis or limb lengthening should be considered.[27] Therefore, it is clinically important to identify risk factors for LLD after a paediatric femur shaft fracture. This study demonstrated that LLD after paediatric femur shaft fractures was significantly associated with fracture stability.

A number of studies have reported overgrowth after paediatric femur shaft fracture and described the associated risk factors. Park et al[20] reported that a length-unstable fracture was a risk factor for overgrowth in patients who underwent TEN or submuscular plating. Dai et al[22] found that length-unstable fractures and low NCD ratios (< 0.8) were significantly associated with limb overgrowth after the application of TEN. Park et al[21] also showed that a low NCD ratio (< 0.8) was a risk factor for femoral overgrowth after TEN. Sulaiman et al[23] showed a strong negative correlation between age and femoral overgrowth following plate fixation. Stilli et al[17] also showed a greater amount of overgrowth in children younger than five years after conservative treatment. However, in this study there were no significant differences in any variables including

Table 5 Risk factors for leg-length discrepancy (≥ 1 cm) after paediatric femur shaft fracture

Variables	Univariable analysis			Multivariable analysis		
	OR	95% CI	p-value*	OR	95% CI	p-value*
Sex	1.6	0.6 to 4.3	0.397			
Age, per year	1.2	1.0 to 1.4	0.068	1.1	0.8 to 1.3	0.690
Body mass index, kg/m^2	1.0	0.9 to 1.2	0.886			
Fracture location						
Middle third *vs* proximal third	0.8	0.3 to 2.2	0.633			
Distal third *vs* proximal third	0.6	0.1 to 7.9	0.706			
Stability length-stable *vs* length-unstable	4.4	1.5 to 13.0	0.007	4.0	1.2 to 12.7	0.020
Injury mechanism high energy *vs* low energy	0.4	0.1 to 1.2	0.100			
Follow-up duration, yrs	1.2	1.0 to 1.4	0.061	1.2	1.0 to 1.4	0.094
Treatment cast *vs* internal fixation	4.5	1.3 to 15.2	0.015	4.0	0.8 to 21.8	0.104

OR, odds ratio; CI, confidence interval
*Logistic regression analysis

Table 6 Risk factors for leg-length discrepancy (≥ 2 cm) after paediatric femur shaft fracture

Variables	Univariable analysis			Multivariable analysis		
	OR	95% CI	p-value*	OR	95% CI	p-value*
Sex	1.9	0.4 to 13.3	0.455	-	-	-
Age, per year	1.0	0.8 to 1.4	0.706	-	-	-
Body mass index, kg/m^2	0.9	0.7 to 1.1	0.521	-	-	-
Fracture location						
Middle third *vs* proximal third	0.3	0.1 to 1.1	0.069	0.3	0.1 to 1.1	0.061
Distal third *vs* proximal third	0.4	0.0 to 5.3	0.533	0.5	0.0 to 8.4	0.672
Stability length-stable *vs* length-unstable	6.4	1.1 to 122.4	0.088	4.5	0.9 to 43.9	0.065
Injury mechanism high energy *vs* low energy	0.9	0.2 to 4.8	0.924	-	-	-
Follow-up duration, yrs	1.2	0.9 to 1.5	0.161	-	-	-
Treatment cast *vs* internal fixation	0.6	0.1 to 2.8	0.565	-	-	-

OR, odds ratio; CI, confidence interval
*Logistic regression analysis

sex, age, fracture location, fracture stability and treatment methods between patients with an overgrowth < 1 cm, and those with an overgrowth ≥ 1 cm. Nascimento et al[28] showed no significant difference in the amount of overgrowth between a TEN group and traction followed by cast group.

There have been few studies investigating LLD and its risk factors after paediatric femur shaft fracture. Hariga et al[29] assessed the LLD in 37 children treated by flexible intramedullary nailing or hip spica cast. They found that LLD was significantly associated with the degree of initial overlap, but not associated with sex, age, fracture type, fracture level or treatment methods. Mutimer et al[30] evaluated the LLD following flexible intramedullary nailing in 17 children. They showed statistically significant LLD (4.3 mm) after TEN in eight children of four to eight years, but no significant LLD (0.1 mm) in children over eight years.

In this study, fracture stability was a significant factor for LLD of ≥ 1 cm. Patients with length-stable fractures had a four-times higher risk of having an LLD ≥ 1 cm than those with length-unstable fractures. Moreover, among nine patients with LLD ≥ 2 cm, eight patients showed length-stable fractures. Length-stable fractures showed less fracture site shortening (2.0 mm) than length-unstable fractures (6.6 mm). However, there was no difference in overgrowth between length-stable and length-unstable fractures. Therefore, length-stable fractures appear to be associated with longer LLD than length-unstable fractures.

Patients who were treated by internal fixation using TEN or plating had a 6.2 mm longer LLD than those who were treated by hip spica cast. Hip spica cast is usually performed with overlapping the proximal and distal fragment of the fracture site. However, for surgical fixation, the goal of reduction is not a 'bayonet apposition', unlike a hip spica cast. Therefore, patients treated by casts had more fracture-site shortening than those who underwent an operation, which might result in this study's results. Among nine patients with a LLD ≥ 2 cm, five were initially treated by TEN, two by plating and two by hip spica casting. We think that some degree of shortening may be desirable to prevent LLD when performing internal fixation for paediatric femur shaft fractures.

There were some limitations to this study. Firstly, the minimum follow-up duration of our cohort was 1.5 years, which may affect the study outcomes. However, there was no significant difference in follow-up duration between patients with a LLD of < 1 cm and those with a LLD of ≥ 1 cm, or between patients with length-stable and those with length-unstable fractures. In addition, follow-up duration was not associated with LLD after paediatric femur shaft fractures. Further long-term follow-up stud-

ies are required. Secondly, we did not have radiographs before the injury; thus, we assumed that limb lengths were equal prior to fracture. Our cohort did not include patients with conditions that cause LLD, such as congenital limb deficiency, neuromuscular disease, tumour and idiopathic hemihypertrophy. Thirdly, our sample size was small, and a sample size estimation was not performed because of the retrospective design of this study. We could not identify the risk factors for LLD ≥ 2 cm because only nine patients had LLD ≥ 2 cm. Further studies with large cohorts are required to provide clinically meaningful information based on sample size calculations.

In conclusion, this study demonstrated fracture stability was significantly associated with LLD after paediatric femur shaft fractures. Therefore, the surgeon should consider the possibility of LLD after length-stable femur shaft fracture in children.

COMPLIANCE WITH ETHICAL STANDARDS

FUNDING STATEMENT

OA LICENCE TEXT

ETHICAL STATEMENT
Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was waived due to the retrospective design of this study.

ICMJE CONFLICT OF INTEREST STATEMENT
The authors declare that they have no conflicts of interest.

AUTHOR CONTRIBUTIONS
TGK: Statistical analysis, Manuscript preparation.
MSP: Study design, Study supervision.
SHL: Study design, Interpretation of data.
KJC: Performed measurements, Interpretation of data.
B-el: Performed measurements, Interpretation of data.
DYK: Interpretation of data.
KHS: Study design, Interpretation of data, Manuscript preparation.

REFERENCES

1. **Waters PM, Skaggs DL, Flynn JM.** *Rockwood and Wilkin's fractures in children*. 9th ed. Philadelphia: Wolters Kluwer Health Inc, 2020.

2. **Ho CA, Skaggs DL, Tang CW, Kay RM.** Use of flexible intramedullary nails in pediatric femur fractures. *J Pediatr Orthop* 2006;26:497-504.

3. **Song HR, Oh CW, Shin HD, et al.** Treatment of femoral shaft fractures in young children: comparison between conservative treatment and retrograde flexible nailing. *J Pediatr Orthop B* 2004;13:275-280.

4. **Assaghir YM.** Titanium elastic nail in femur fractures as an alternative to spica cast in preschoolers. *J Child Orthop* 2012;6:505-511.

5. **Mahajan J, Hennrikus W, Piazza B.** Overgrowth after femoral shaft fractures in infants treated with a Pavlik harness. *J Pediatr Orthop B* 2016;25:7-10.

6. **Nascimento FP, Santili C, Akkari M, et al.** Short hospitalization period with elastic stable intramedullary nails in the treatment of femoral shaft fractures in school children. *J Child Orthop* 2010;4:53-60.

7. **Abdelgawad AA, Sieg RN, Laughlin MD, Shunia J, Kanlic EM.** Submuscular bridge plating for complex pediatric femur fractures is reliable. *Clin Orthop Relat Res* 2013;471:2797-2807.

8. **Li Y, Hedequist DJ.** Submuscular plating of pediatric femur fracture. *J Am Acad Orthop Surg* 2012;20:596-603.

9. **Andreacchio A, Marengo L, Canavese F, Pedretti L, Memeo A.** Comparison between external fixation and elastic stable intramedullary nailing for the treatment of femoral shaft fractures in children younger than 8 years of age. *J Pediatr Orthop B* 2016;25:471-477.

10. **Sink EL, Hedequist D, Morgan SJ, Hresko T.** Results and technique of unstable pediatric femoral fractures treated with submuscular bridge plating. *J Pediatr Orthop* 2006;26:177-181.

11. **Sink EL, Faro F, Polousky J, Flynn K, Gralla J.** Decreased complications of pediatric femur fractures with a change in management. *J Pediatr Orthop* 2010;30:633-637.

12. **Khamis S, Carmeli E.** The effect of simulated leg length discrepancy on lower limb biomechanics during gait. *Gait Posture* 2018;61:73-80.

13. **Rannisto S, Okuloff A, Uitti J, et al.** Leg-length discrepancy is associated with low back pain among those who must stand while working. *BMC Musculoskelet Disord* 2015;16:110.

14. **Campbell TM, Ghaedi BB, Tanjong Ghogomu E, Welch V.** Shoe lifts for leg length discrepancy in adults with common painful musculoskeletal conditions: a systematic review of the literature. *Arch Phys Med Rehabil* 2018;99:981-993.e2.

15. **Assaghir Y.** The safety of titanium elastic nailing in preschool femur fractures: a retrospective comparative study with spica cast. *J Pediatr Orthop B* 2013;22:289-295.

16. **Nordin S, Ros MD, Faisham WI.** Clinical measurement of longitudinal femoral overgrowth following fracture in children. *Singapore Med J* 2001;42:563-565.

17. **Stilli S, Magnani M, Lampasi M, et al.** Remodelling and overgrowth after conservative treatment for femoral and tibial shaft fractures in children. *Chir Organi Mov* 2008;91:13-19.

18. **Etchebehere EC, Caron M, Pereira JA, et al.** Activation of the growth plates on three-phase bone scintigraphy: the explanation for the overgrowth of fractured femurs. *Eur J Nucl Med* 2001;28:72-80.

19. **Martin-Ferrero MA, Sanchez-Martin MM.** Prediction of overgrowth in femoral shaft fractures in children. *Int Orthop* 1986;10:89-93.

20. **Park KH, Park BK, Oh CW, et al.** Overgrowth of the femur after internal fixation in children with femoral shaft fracture-a multicenter study. *J Orthop Trauma* 2020;34:e90-e95.

21. **Park SS, Noh H, Kam M.** Risk factors for overgrowth after flexible intramedullary nailing for fractures of the femoral shaft in children. *Bone Joint J* 2013;95-B:254-258.

22. **Dai CQ, Yang J, Guo XS, Sun LJ.** Risk factors for limb overgrowth after the application of titanium elastic nailing in the treatment of pediatric femoral fracture. *J Orthop Sci* 2015;20:844-848.

23. **Sulaiman AR, Joehaimy J, Iskandar MA, et al.** Femoral overgrowth following plate fixation of the fractured femur in children. *Singapore Med J* 2006;47:684-687.

24. **Flynn JM, Hresko T, Reynolds RA, et al.** Titanium elastic nails for pediatric femur fractures: a multicenter study of early results with analysis of complications. *J Pediatr Orthop* 2001;21:4-8.

25. **Lee KM, Lee J, Chung CY, et al.** Pitfalls and important issues in testing reliability using intraclass correlation coefficients in orthopaedic research. *Clin Orthop Surg* 2012;4:149-155.

26. **Bonett DG.** Sample size requirements for estimating intraclass correlations with desired precision. *Stat Med* 2002;21:1331-1335.

27. **Herring JA.** *Tachdjian's pediatric orthopaedics.* 5th ed. Philadelphia, PA: Elsevier, 2014.

28. **Nascimento FP, Santili C, Akkari M, et al.** Flexible intramedullary nails with traction versus plaster cast for treating femoral shaft fractures in children: comparative retrospective study. *Sao Paulo Med J* 2013;131:5-12.

29. **Hariga H, Mousny M, Docquier PL.** Leg length discrepancy following femoral shaft fracture in children: clinical considerations and recommendations. *Acta Orthop Belg* 2011;77:782-787.

30. **Mutimer J, Hammett RD, Eldridge JD.** Assessing leg length discrepancy following elastic stable intramedullary nailing for paediatric femoral diaphyseal fractures. *Arch Orthop Trauma Surg* 2007;127:325-330.