Open Reduction and Internal Fixation for Displaced Salter-Harris type II Fractures of the Distal Tibia: A Retrospective Study of Eighty-Five Cases in Children

Quanwen Yuan
Soochow University Affiliated Children's Hospital
Yunfang Zhen
Soochow University Affiliated Children's Hospital
Zhixiong Guo
Soochow University Affiliated Children's Hospital
Fuyong Zhang
Soochow University Affiliated Children's Hospital
Jianfeng Fang
Soochow University Affiliated Children's Hospital
Zhenhua Zhu
Soochow University Affiliated Children's Hospital
Lunqing Zhu
Soochow University Affiliated Children's Hospital
Xiaofang Shen
Soochow University Affiliated Children's Hospital
Chunhua Yin
Soochow University Affiliated Children's Hospital
Yao Liu
Soochow University Affiliated Children's Hospital
Feng Yao
Soochow University Affiliated Children's Hospital
Lin Wu
Soochow University Affiliated Children's Hospital
Xiaodong Wang (orthowxd@163.com)
Soochow University Affiliated Children's Hospital

Research article

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Abstract

Background: The treatment for displaced Salter-Harris □ distal tibia fractures remains controversial. The purpose of this study was to evaluate the rate of premature physeal closure (PPC) and to identify the risk factors treated by open reduction and internal fixation.

Methods: We reviewed the charts and radiographs of patients with Salter-Harris □ fractures of the distal tibia with displacement >3mm between 2012 and 2019. Open reduction and internal fixation was performed for all patients. Patients were followed up for a minimum of 4 months. Contralateral ankle radiograph or CT scans were obtained if there was any evidence of premature physeal closure. Any angular deformity or shortening of the involved leg was documented.

Results: A total of 85 patients with a mean age of 12.3years were included in the study. The mean initial displacement was 8.5 mm. All patients but one were treated within seven days after injury and the mean interval was 3.7 days. SER injuries occurred in 65 patients (76.5%), PER in 17 (20.0%), and SPF in three (3.5%). The rate of PPC was 29.4% and two patients with PPC had varus deformities. The rate of PPC was significantly greater in patients with associated fibular fracture as compared with those with intact fibular (P=0.005). Patient age, gender, injured side, mechanism of injury (only SER vs PER), amount of initial displacement, interval from injury to surgery, or energy of injury did not affect the rate of PPC significantly.

Conclusions: PPC is a common complication for displaced S-H □ distal tibia physeal fractures. We suggest that open reduction internal fixation is an effective choice to reduce the risk of PPC. The presence of concomitant fibula fracture was associated with PPC.

Background

Salter-Harris type □ (S-H □) distal tibia physeal fracture is the most frequent ankle injury in children, accounting for approximately 32–60% [1, 2, 3]. The goal of treatment of distal tibia physeal fractures is to prevent premature physeal closure (PPC) and subsequent growth disturbances. Theoretically, S-H □ distal tibia physeal fracture carries a lower rate of growth disturbance, contributing to the fracture line being in the hypertrophic zone [4]. Privous literatures reported that the incidence of PPC is 2–5% [5, 6, 7], based on the minimal displacement or relative shorter follow-up period. Recently, however, several articles have demonstrated a higher rate of PPC, ranged from 20–75%, regardless of the treatment options [1, 3, 8, 9, 10, 11, 12]. Moreover, PPC was far more common in S-H □ distal tibia physeal fractures than in S-H □ and □ fractures, representing up to 60% of all PPCs [1, 2].

For no or minimal displaced fractures, long leg cast was underwent for 4–6 weeks. The optimal treatment for displaced S-H □ distal tibia fractures is still controversial, even at the same institution [3, 8, 10]. Barmada et al. [3] reported that the incidence of the PPC will increase by 3.5 fold in presence of residual gap and they recommended open reduction and removal of the interposed periosteum to decrease the risk of PPC. Similarly, Kling et al. [12] reviewed eight children with S-H □ fractures reduced by closed manipulation and found physeal growth arrest developed in six. However, Russo et al. [8] recommended closed reduction for all displaced S-H ▯ fractures and those with postreduction displacement of > 4mm were treated with open reduction and internal fixation (ORIF). They reported a PPC rate of 53% in their 38 cases and concluded that ORIF could not reduce the incidence of PPC. Furthermore, multiple attempts of reduction may result in further damage of the growth plate [13, 14].

At our institution, S-H ▯ fractures of the distal tibia with initial displacement > 3mm were reduced no more than once at the time of injury and ORIF was undergone to remove the inerposed periosteum and to decrease the iatrogenic physeal injury. The purpose of this study sought to evaluate the rate of PPC and to identify the risk factors.

Methods

This retrospective study was approved by ethic committee board of our hospital. The medical records and radiographs of patients treated at our institution for S-H ▯ fractures of the distal tibia with open epiphyses were reviewed between 2012 and 2019. Patients with fracture displacment < 3mm,

pathological fractures, open fractures, or < 4 months of follow-up were excluded. The parameters that were recorded included sex, age, side of injury, mechanism of injury, initial fracture displacement, the interval between the injury and surgery, and length of follow-up. The fracture displacement was measured in millimeters as the largest amount of displacement between the epiphysis and metaphysis on radiograph or computed tomography (CT). The mechanism of injury was classified based on Dias-Tachdjian system [15], including three fracture types: pronation-eversion external rotation (PER), supination-external rotation (SER), and supination-plantar flexion (SPF) injuries. We considered sports-related injuries and falls from < 1.0m as low energy and motor vehicle accident, including e-bike accident, falls from ≥ 1.0m as high energy.

Given severe displacement of the fracture, open reduction was performed under general anesthesia to obtain an anatomic reduction. At the time of surgery, the anterolateral approach approximately 3 to 5cm was made and the periosteum and other soft tissue interposed in the physeal seperation were removed prior to reduction, as described by Mosca [13]. The reduction was obtained via gentle manipulation reversing the direction of the original force that caused the injury. Following reduction, fixation was performed with either 2–3 1.6mm smooth Kirschner wires that crossed the physis percutaneously or screws placed in the metaphysis 0.5-1.0cm to the physis (parallel to the physis). A short leg cast was applied, which was retained for approximately four to six weeks. Hardware was removed routinely. The wires were removed 4–6 weeks and screws after approximately six months postoperatively. At each visit, anteroposterior (AP) and lateral radiographies were taken to recognize PPC. Contralateral ankle radiograph or CT scans were obtained if there was any evidence of PPC. Any angular deformity or shortening of the involved leg was documented.

Descriptive statistics including means and frequencies were calculated for each of the examined variables. χ^2 analysis was used for categorical variables and student t tests were performed to compare continuous variables. Data were analyzed using SPSS software, version 20.0 (SPSS Inc., Chicago, IL). A P-value < 0.05 was considered statistically significant.

Results

The patient demographic data were documented in Table 1. Eighty-five patients, 65 boys and 20 girls, were included for review. The average age was 12.3 ± 2.1 years(range, 3.9 to 15.8 years). Forty-eight fractures involved the right leg and 37 the left. The mean initial displacement was 8.5 ± 4.0mm (range, 3.2–25 mm). Four patients underwent surgery within one day after injury, 80 between two and seven days, and one on the ninth. The mean interval was 3.7 ± 1.6 days (range, 1–9 days). None of the patients suffered deep skin infection and one superficial skin infection. The mean follow-up period was 7.9 ± 3.6 months (range, 4–25 months).

Table 1
Demographic data of the 85 children

Variables	Results
Age (y)	12.3 ± 2.1
Gender	
Female	20
Male	65
Injured side	
Right	48
Left	37
Mechanism of injury	
SER	65
PER	17
SPF	3
Concomitant fibula fracture	
Yes	59
No	29
Initial displacement(mm)	8.5 ± 4.0
Interval (d)	3.7 ± 1.6
Energy of injury	
High	25
Low	60
Follow-up(m)	7.9 ± 3.6
PPC (%)	29.4

SER, supination external rotation; PER, pronation eversion external rotation; SPF, supination plantar flextion; PPC, premature physeal closure.

Fifty-six patients (65.9%) had concomitant fibula fractures and 29 (34.1%) had not. SER injuries occurred in 65 patients (76.5%), PER in 17 (20.0%), and SPF in three (3.5%). There were 60 patients suffering from low-energy injury and 25 high-energy injury. There was statistically significant difference in the initial displacement between the patients associated with and without fibula fractures(P = 0.001), and between the high-energy and low-energy of injury($P = 0.035$). However, there were no significant differences in the initial displacement between mechanism of injury (SER vs PER), and between the injured sides (Table 2).

Table 2
The correlation between the amount of initial fracture displacement and the concomitant fibula fracture, injured side, energy of injury and mechanism of injury.

Variables	Amount of initial displacement	*P*
Concomitant fibula fracture Yes	9.6 ± 4.3	**0.001**
No	6.4 ± 2.3	
Injured side Right Left	9.0 ± 4.8 7.9 ± 2.6	0.224
Energy of injury		
High	7.3 ± 2.7	**0.035**
Low	9.0 ± 4.4	
Mechanism of injury		
SER	8.5 ± 4.3	0.069
PER	8.1 ± 2.9	

SER, supination external rotation; PER, pronation eversion external rotation.

At finial visit, twenty-five patients developed PPC and the rate of PPC was 29.4% (Table 1, Fig. 1, 2). Out of 25 patients with PPC, two had varus deformities (10 degrees, 15 degrees) (Fig. 3).

Variables associated with PPC were evaluated. When comparing patients with PPC and without PPC, the incidence of PPC was found to be significantly greater in patients with associated fibular fracture as compared with those with intact fibular ($P = 0.005$). However, there were no significant correlations between the PPC rate and patient age ($P = 0.76$), gender ($P = 0.62$), injured side ($P = 0.05$), mechanism of injury (only SER vs PER) ($P = 0.98$), amount of initial displacement ($P = 0.41$), interval from injury to surgery ($P = 0.92$), and energy of injury ($P = 0.92$). (Table 3). The PPC rate by the interval from injury to surgery was 50% within the first day, 27.5% between 2 and 7 days, 100% on the ninth, respectively. No statistical analysis was conducted due to the small sample.

Table 3
Variables associated with PPC for displaced S-H Ⅱ distal tibia fractures.

Variables	**PPC (n = 25)**	**No PPC (n = 60)**	***P***
Age (y)	12.1 ± 2.3	12.3 ± 2.0	0.76
Gender			
Female	5	15	0.62
Male	20	45	
Injured side			
Left	15	22	0.05
Right	10	38	
Mechanism of injury			
SER	19	46	0.98
PER	5	12	
SPF	1	2	
Concomitant fibula fracture			
Yes	22	34	**0.005**
No	3	26	
Amount of initial displacement(mm)	9.0 ± 3.2	8.3 ± 4.3	0.41
Interval(d)	3.6 ± 1.9	3.7 ± 1.4	0.92
Energy of injury			
High	7	18	0.92
Low	18	44	
Follow-up(m)	8.9 ± 3.4	7.6 ± 3.7	0.12

SER, supination external rotation; PER, pronation eversion external rotation; SPF, supination plantar flextion; PPC, premature physeal closure.

Discussion

There have been numerous reports of the management in regarding to various displacement of S-H Ⅱ distal tibia physeal fractures [1, 3, 8, 10, 11, 12]. However, there has been sporadic report composing exclusively of severe displaced fracture. To the best of our knowledge, this study represents the largest series, in one institution, involving S-H □ distal tibia fractures alone with initial displacement of > 3mm treated by ORIF.

For these fractures, several retrospective cohort studies [8, 9, 16, 17] and one systematic review [18] demonstrated that there was no significant difference in PPC rate between open reduction and closed reduction. Some of these studies, however, were performed among varying displacement of the fractures. Moreover, there was a lack of random controlled study for displaced fractures. Recently, a magnetic resonance imaging study showed that periosteum was entrapped in all 15 displaced S-H □ distal tibia fractures [19]. And up to 60% of cases had residual displacement > 2mm after closed reduction [11]. We attempted to minimize reduction attempts prior to operation and remove the entrapped periosteum and apply gentle manipulation during operation so as to avoid further damage to the physis [16, 20]. The incidence of PPC was 29.4% in our series, which was less than that reported in literatures. Russo et al. [8] showed a 53% PPC rate in S-H □ fractures with displacement > 2mm treated with ORIF after failure of closed reduction.

Previous studies have shown that multiple factors were attributable to PPC, including initial or residual displacement [1, 6, 11, 16, 21], mechanism of injury [9, 10, 22], age at injury [16], reduction attempts [1, 14]. In our study, we found no significant correlation between the rate of PPC and mechanism of injury. This may be associated with the relative less proportion of PER that was more susceptible to PPC [9, 10, 22]. Similarly, no significant correlation between PPC and the energy of injury was found. Generally, it was thought that high-grade injury to the physis was associated with the occurrence of PPC [1, 11]. Margalit et al. [11] categorized falls from ≥ 1.5m or a motor vehicle accident as high-energy injury and demonstrated that patients with high-grade injury had 12 times greater of PPC. In our series, we categorized falls from ≥ 1m or motor or e-bike vehicle accident as high-energy injury, from which the growth plate may not suffer sufficient force.

Dias and Tachdjian [15] emphasized that the abnormal force which caused the injuries would sum and such injuries always occurred in a sequence of grades. In our series, we found that the amount of initial displacement in patients with associated fibula fracture was greater than that with intact fibula. Although Spiegel et al. [21] found no association between associated fibula fracture and PPC, we did find significant association between the rate of PPC and associated fibular fracture, which was in accordance to previous literatures [2, 5, 17]. We speculated that injuries with associated fibula fracture may lead to more severe damage to the tibial growth plate than that with intact fibula.

The timing of surgery for physeal fracture is of paramount importance. Petratos et al. [23] suggested that reduction should be performed within one day of damage and the probability of growth arrest will be six fold greater, if the fracture was treated beyond 24 hours. In the present study, the mean interval was delayed to 3.7 days after injury due to significant swelling of the ankle. However, there were two patients with varus deformity of the ankle who were treated on the sixth and ninth day after injury. Given the rarity of the deformity, we cannot conclude whether this isolated case was due to the delayed reduction or not. But we think the earlier the reduction, the lower rate of PPC.

Although we have paid more attention to the displaced S-H □ fractures, the incidence of PPC, as shown in our study, is still higher than anticipated. We thought this may be due to the shearing force on the Kump's pump of the physis or the crushing force on the physis at the time of the injury [24].

A limitation of our present study was only a retrospective cohort study. A randomized controlled study should be performed to look at displaced fractures treated surgically vs non-surgically to investigate the risk factors of PPC. Another limitation was less length of follow-up. The average length from injury to diagnosis of PPC was 7 months, even two years after injury [5, 8]. Therefore, the patients with S-H □ distal tibia fractures should be followed for at least one year to identify the PPC early.

In conclusion, open reduction internal fixation is beneficial to reduce the risk of PPC for displaced S-H □ distal tibia physeal fractures. The presence of associated fibula fracture plays an important role in the fracture outcome.

Abbreviations

S-H □: Salter-Harris type □

PPC: premature physeal closure

SER: supination-external rotation

PER: pronation-eversion-external rotation

SPF: supination-plantar flextion

ORIF: open reduction and internal fixation

AP: anteroposterior radiograph

CT: computed tomography

Declarations

Ethics approval and consent to participate in present study was approved by the Ethics Committee of Children's Hospital of Soochow University.

Consent for publication

Not applicable.

Availability of data and material

All data generated or analysed during this study are included in this manuscript.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

XW contributed to the study design and is the corresponding author. QY, FZ and ZG contributed to the study design, data analysis and interpretation, and manuscript draft. FZ, JF, ZZ, LZ and XS contributed to the data collection and analysis. CY, YL, FY and LW contributed to the literature search and manuscript revision. All authors have read and approved the final manuscript.

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Figures

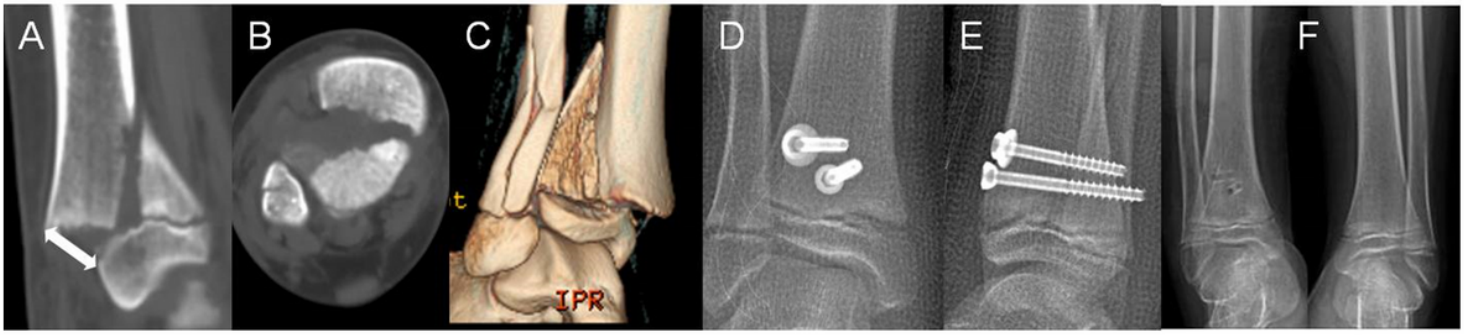

Figure 1

A 12-year-old boy with a S-H □ distal tibia fracture. A,B and C, Sagittal view, axial view and 3D demonstrated 15mm displacement of the fracture (white double arrow). D and E, AP and lateral radiographs demonstrated the anatomical reduction immediately post operatively. F, AP radiograph of bilateral ankle joints taken at 9-month follow-up showed symmetrically open physis as compared with the opposite side.

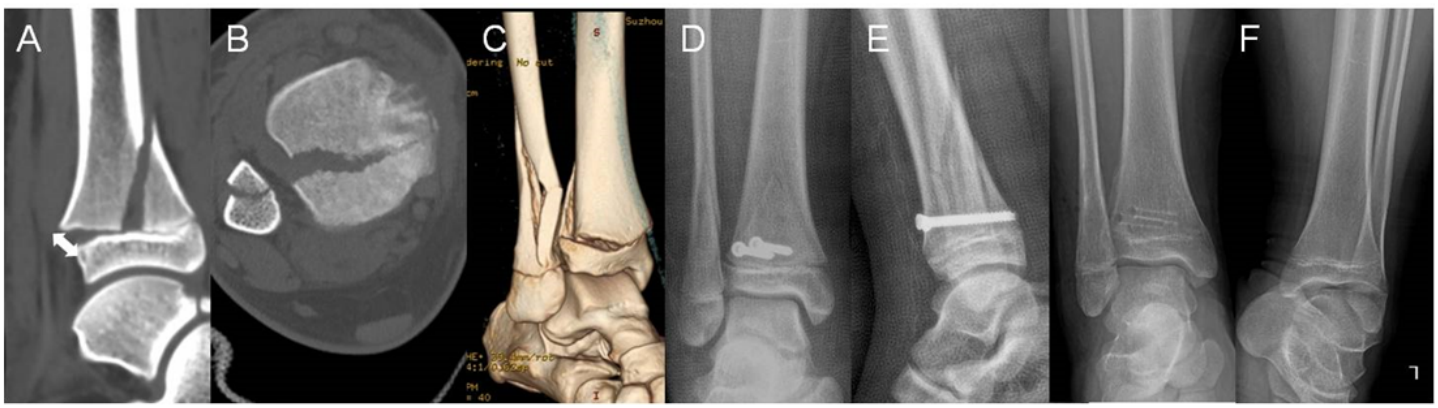

Figure 2

A 13-year-old boy with a S-H □ distal tibia fracture. A, B and C, Sagittal view, axial view and 3D demonstrated 8 mm displacement of the fracture (white double arrow). D and E, AP and lateral radiographs showed the anatomical reduction immediately post operatively. F, AP radiograph of bilateral ankle joints obtained 7 months after ORIF showed PPC, without ankle deformity.

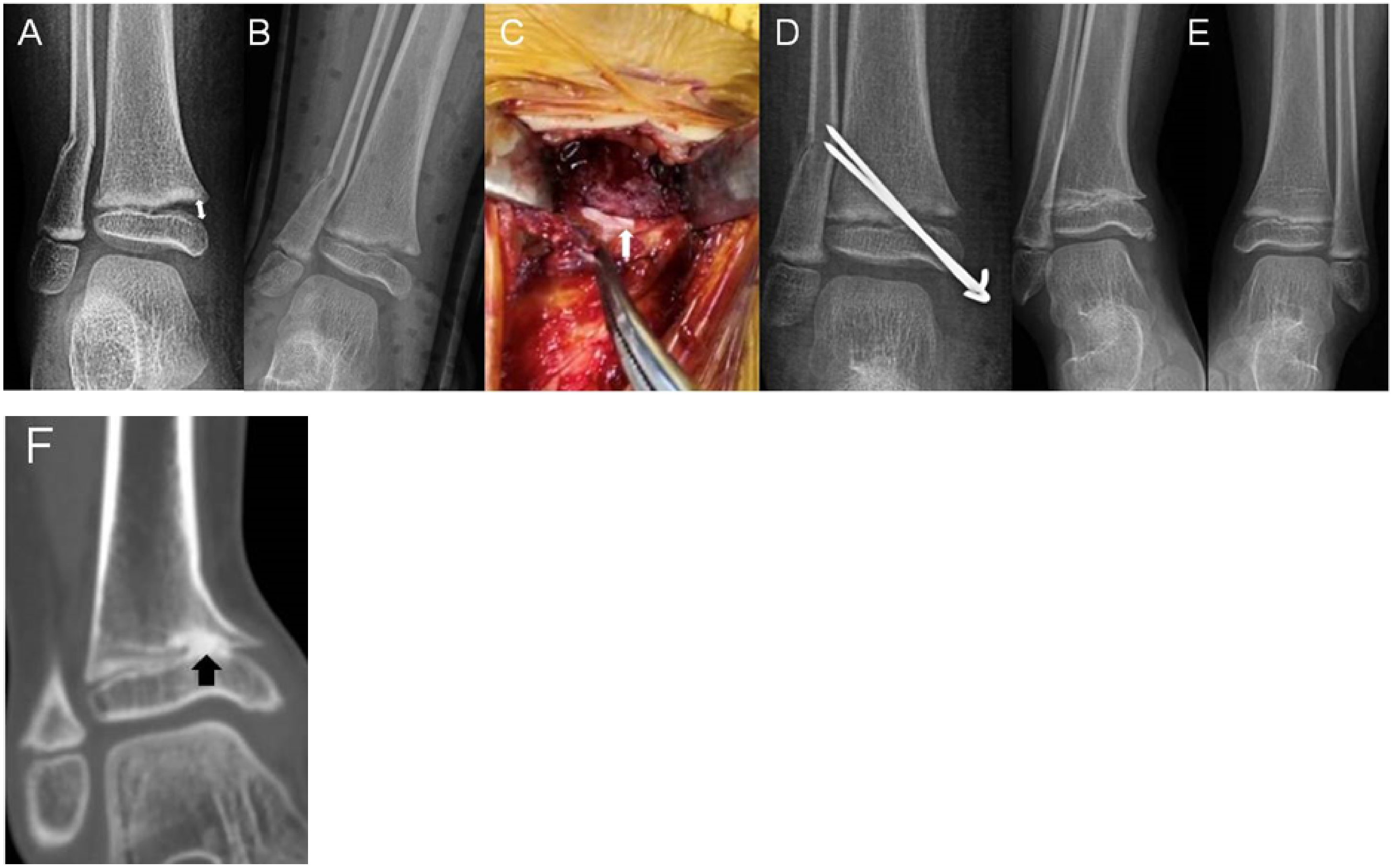

Figure 3

A 3.9-year-old girl with a S-H ▯ distal tibia fracture. A, AP radiograph showed 7 mm displacement of the fracture (white double arrow). B, AP radiograph obtained 8 days after closed reduction showed the significant residual gap. C, Interposed periosteum was shown after open reduction (white arrow). D, AP radiograph demonstrated the reduction immediately post operatively. E, AP radiograph of bilateral ankle joints obtained 14 months after treatment showed a partial premature arrest and a varus deformity (15 degrees). F, Coronal view detected the bone bridge (black arrow).