

## Treatment of Post-traumatic Pediatric Ankle Varus Deformity with Physeal Bar Resection and Hemi-Epiphysiodesis\*

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**Summary:** Children presenting with partial physeal arrest and significant remaining growth may benefit from physeal bar resection, although the operation is a technique demanding procedure. This study evaluates the treatment of post-traumatic pediatric ankle varus deformity using physeal bar resection and hemi-epiphysiodesis with the assistance of two operative methods. Forty-five patients presenting with a distal tibial medial physeal bridge as well as ankle varus deformity following traumatic ankle physeal injury between 2009 and 2017 were followed. These patients were treated with physeal bar resection and hemi-epiphysiodesis, with the assistance of either fluoroscopy (10 cases) or intraoperative three-dimensional navigation (35 cases). Of the 45 cases, the median age was 9.0 years (range: 3–14 years) with 28 male and 17 female patients. The median of pre-operation ankle varus angle was 20 degrees (IQR 15–25) and 5 degrees (IQR 0–20) at the time of final follow up, representing a statistically significant difference ( $P < 0.05$ ). No differences were observed with regards to age, gender, and surgical history between effective group and ineffective group ( $P > 0.05$ ). The median of pre-operative ankle varus angles of the navigation and fluoroscopy groups were both 20 degrees ( $P > 0.05$ ). The median correction angle of the navigation and fluoroscopy groups was 10 and 15 degrees, respectively ( $P > 0.05$ ). Our results indicate that physeal bar resection and hemi-epiphysiodesis are effective treatments for correcting ankle varus deformity due to traumatic medial physeal arrest of the distal tibia. We observe no difference in outcome between fluoroscopy group and three-dimensional navigation group during the procedures.

**Key words:** ankle varus; physeal bar resection; navigation

Ankle fractures are the second most common growth plate fracture in children, and one of top 10 causes of pediatric orthopedic hospital admissions<sup>[1]</sup>. These injuries involving the growth plate of the distal tibia is of particular concern. Growing children have open physes that are relatively weak compared to surrounding bone and ligaments, making them particularly susceptible to damage from traumatic injuries. Even in cases of Salter-Harris type I or II fractures of the distal tibia which have previously been considered as low risk, high rates of partial growth arrest have been reported (35.3%–39.6%)<sup>[2–5]</sup>. Once the physeal bar of the distal tibia has formed, ankle deformity and shortening of the lower extremity can

occur<sup>[5–7]</sup>. The load bearing area of the ankle is smaller than that of the knee, leading to an increase in load per unit area. Kimizuka<sup>[8]</sup> reported that when a force of 500 N was applied, the area of contact in the ankle was 350 mm<sup>2</sup> compared with 1100 mm<sup>2</sup> in the hip and 1120 mm<sup>2</sup> in the knee. For this reason, osteoarthritis (OA) readily develops once a structural abnormality develops in the ankle.

Medial side growth arrest of the distal tibia results in ankle varus, or limb-length discrepancy, and relative fibular overgrowth, often with lateral impingement<sup>[5]</sup>. In children who are approaching skeletal maturity, osteotomy can correct the angular deformity and reestablish the mechanical axis. However, in younger children with substantial physeal growth remaining and a partial physeal bar, the deformity may recur soon after osteotomy. In this situation, bar resection can be attempted, although it is a demanding surgical procedure. This study evaluates the outcomes of pediatric patients with post-traumatic ankle varus deformity treated with physeal bar resection and hemi-epiphysiodesis.

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## 1 MATERIALS AND METHODS

### 1.1 General Information

From June 2009 to September 2017, 45 patients with medial side growth arrest of the distal tibial physis underwent physeal bar resection and hemi-epiphysiodesis. Totally, 17 patients were female and 28 male, forming an average age of 9.0 years (range: 3–14 years). Clinical and radiological evidence of medial distal tibial physeal growth arrest was suggested in all patients. Standard ankle joint radiographs were taken in the anteroposterior and lateral views. CT and magnetic resonance image (MRI) were used to determine the existence and the area of a physeal bar. No patient had active infections at the time of surgery, and all cases had a previous history of distal tibial physeal injury. In total, 24 cases had previous fracture reduction and internal fixation operations due to trauma, and rest 21 cases had received conservative treatment and therefore had no operation history. The average duration from the previous fracture to the physeal bar resection operation was 28 months (ranging from 20 to 42 months). Resection of a physeal bar is indicated when less than 30% of the physis is damaged and more than two years of growth remain. The physeal bar resection operation was performed with the assistance of either fluoroscopy (10 cases) or intraoperative three-dimensional (3D) navigation (35 cases).

### 1.2 Surgical Technique

The patients were in a supine position on a radiolucent table with a tourniquet placed on the proximal end of the lower extremity. With the patient prepared and draped, fluoroscopy or navigation was brought into the field.

In X-ray fluoroscopy group, with anteroposterior and lateral fluoroscopic imaging, the growth plate and bone bridge were confirmed. A direct approach to the bone bridge was used for peripheral bars. Central physeal bar resection is typically performed by approaching the physis through the metaphysis adjacent to the physeal bar. Under fluoroscopic guidance, a motorized burr was used to carefully remove all of the bone bridge until normal physis was encountered.

In intraoperative 3D C-arm navigation group, the tracker was fixed on the proximal tibia. Images were obtained by simultaneous reconstruction of the 3D images collected during the operation by electric C-arm (SIREMOBIL Iso-C, Siemens, Germany). The images were transferred to the navigation system, which processed them automatically. The registration error, automatically calculated by the navigation system, and the accuracy of the images was verified using a navigational pointer. Using this system, the location of the physeal bar was confirmed, and the entry point and trajectory of a drill hole directed toward the physeal bar were mapped. Under real time

3D monitoring navigation guidance, a motorized burr was used to carefully remove bone until the physeal bar was reached, then the area of resection was expanded until normal physis was encountered. After resection, the void was then filled with bone wax to prevent recurrence of a bone bridge secondary to postoperative bleeding. The hemi-epiphysiodesis was conducted in the lateral distal tibia with eight plates and in the distal fibular with either screws or eight plates. After the tourniquet was released, the incision was closed after confirmation of the absence of bleeding.

### 1.3 Postoperative Management

A short leg plaster was applied for 4 weeks following surgery. After this, ankle movement was permitted as tolerated by the patient. Eight weeks after operation, the patient was allowed to place full weight on the leg. Radiograph data were obtained to evaluate the effect of operation during follow-up (fig. 1). The angle between the mechanical axis of the tibia and the ankle joint was measured. Ankle varus angle was defined as 90 degrees subtracted this angle. The effectiveness was defined as the ankle varus angle being decreased by 10 degrees or more.



**Fig. 1** A typical case (a 12 years old boy) of physeal bar resection on the medial side of distal tibia with the assistance of 3D navigation

A: Anteroposterior radiograph of the ankle demonstrated a medial physeal bar and ankle varus; B: Anteroposterior radiograph of the ankle just after physeal bar resection and hemi-epiphysiodesis; C: 18 months post-operation radiograph demonstrated good general alignment.

### 1.4 Statistical Analysis

We performed descriptive statistics and compared differences for continuous data (e.g. the angle between the mechanical axis and the joint before and after surgery) using parametric (e.g. paired *t* test for the change in ankle angle pre and post operation) and nonparametric tests (e.g. Kolmogorov-Smirnov test) considering central tendency, dispersion, and distribution. A Kolmogorov-Smirnov test was performed to test for normality of the distribution of variables (e.g. the angle between the mechanical axis and the joint before and after surgery). We used Fisher's

test to compare the difference for categorical data (e.g. surgical method and treatment history), considering the limited number of cases. In addition, we transformed continuous data, such as age, into categorical data by grouping patients into  $\geq 8$  years old or  $< 8$  years categories to compare the overall effectiveness of the surgery. Statistical analysis was performed by SAS 9.2 (SAS Institute, Cary, USA) using two-tailed tests, with a significant level as  $\alpha=0.05$ .

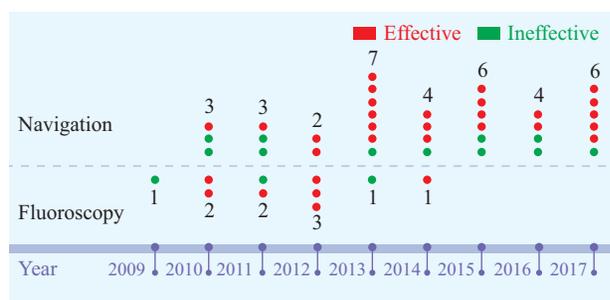
## 2 RESULTS

The characteristics of the 45 patients are shown in table 1.

**Table 1 Characteristics of the participants (n=45)**

Characteristics	n	Percentage (%)
Age (mean, years)	9.0	–
Gender		
Male	28	62.2
Female	17	37.8
Surgical mode		
Navigation	35	77.8
Fluoroscopy	10	22.2
Result		
Effective	31	68.9
Ineffective	14	31.1
Having operation history		
Yes	24	53.3
No	21	46.7

The ankle varus angle post the surgery was statistically significantly improved ( $S=264.0$ ,  $P<0.001$ ). We didn't observe a statistically significant difference in overall effectiveness rate between the navigation group and the fluoroscopy group. However, the technical advance does help more children benefit from the operation and the number of operations increased drastically over the recent years (fig. 2). There was no difference in overall effectiveness rate between the surgical treatment group and the conservative treatment group ( $P=0.121$ ), as well between  $\geq 8$  years old group and  $< 8$  years old group ( $P=0.325$ ).



**Fig. 2** Annual number of cases of two different surgical modes from 2009 to 2017 (n=45)

Of the 45 cases, the median of pre-operation ankle varus angle and at the last follow-up time was 20 degrees (IQR 15–25) and 5 degrees (IQR 0–20), respectively, making the difference between pre- and post-surgery significant ( $P<0.05$ ). Totally, 31 cases had effective treatment, but the treatment was ineffective in 14 cases. The age and gender were similar between the effective and ineffective groups ( $P>0.05$ ). When considering surgical history and age, there were also no significant differences between the effective and ineffective groups ( $P>0.05$ ). The median pre-operative ankle varus angles of the navigation group and fluoroscopy group were both 20 degrees. The median of correction angle of the navigation group and fluoroscopy group was 10 and 15 degrees, respectively ( $P>0.05$ ) (table 2).

**Table 2 Comparison of the effectiveness [n (%)]**

	Effective	Ineffective	P*
Surgical modes			
Navigation	24 (68.6)	11 (31.4)	1.000
Fluoroscopy	7 (70.0)	3 (30.0)	
Operation history			
Yes	14 (58.3)	10 (41.7)	0.121
No	17 (81.0)	4 (19.0)	
Age (years)			
$< 8$	6 (50.0)	6 (50.0)	0.325
$\geq 8$	22 (66.7)	11 (33.3)	

\*Note: two-sided probability was used.

## 3 DISCUSSION

Physal bars form when nearby cartilage is breached as a result of infection, trauma, tumors, irradiation, or thermal burns. This causes the trabecular bone to heal continuously between the epiphysis and the metaphysis across the physis. In most situations, once a physal bar has formed, limb length discrepancy, angular deformity, or both will continue to develop as long as the patient is skeletally immature<sup>[9, 10]</sup>. Partial growth arrest, if left untreated, results in angular deformity and/or shortening and may have a devastating effect on limb alignment and adjacent joint function and longevity. If corrective osteotomy or limb lengthening is performed before skeletal maturity, the deformity recurs with time. Partial physal arrest in a child with significant growth remaining may benefit from takedown of the bony bar. Treatment of physal arrest is a technically demanding procedure—and not always successful—but critically necessary to reestablish growth in the extremity of a child who has sustained traumatic growth plate closure<sup>[11]</sup>.

Identification of the exact location of the bar is critical to resection. Caution must be taken to avoid both excessive removal of physal cartilage and

inadequate removal of bridging bone. The location and area of a physal bar may be evaluated using plain radiography, CT or MRI<sup>[12, 13]</sup>. Carlson *et al*<sup>[14]</sup> described a method of producing a schematic cross-sectional map on graph paper using data obtained from biplanar polytomography. This helped identify lesions that could be treated surgically, and aided in the planning of operations. However, the map has some limitations. The precise extent of the lesion is difficult to identify under intraoperative fluoroscopy guidance, even though the location and size of the bar have been determined.

Traditional X-ray fluoroscopy is used commonly for intraoperative visualization but is possible in only one plane at a time. This necessitates repeated C-arm movements during surgery. X-ray radiography should be performed with the beam centered on the growth plate and tilted in the same plane. Before an attempt at excision, the extent and location of the bar should be clearly delineated. In our report, there were only 10 cases that underwent this technique because of this difficulty.

The 3D fluoroscopy-based navigation system has increasingly been used in various fields of orthopedic surgery, such as spine, joint, trauma, and skeletal tumor surgeries<sup>[15, 16]</sup>. It is a useful tool in pediatric orthopedics when employed in the treatment of physal bar resection. Although MRI and CT scans could help in developing a pre-operation plan, their intra-operative value is limited. Extremely accurate intra-operative identification of the physal bar is necessary to perform precise resection. The advent of intraoperative 3D fluoroscopy-based navigation system permits accurate localization with the advantage of obtaining intraoperative real-time 3D images and automatic registration. This enables intra-operative identification of the extent of a physal bar, and allows more accurate surgery<sup>[17]</sup>. After employing intraoperative 3D C-arm navigation, we treated more cases and were able to obtain the same positive results.

It is well known that physal bar resection is a demanding technique, and there are only sporadic reports of its use in the treatment of partial growth arrest of the distal tibia<sup>[18–20]</sup>. To our knowledge, this is the largest study on the effects of physal bar resection and epiphysodesis on post-traumatic pediatric ankle varus deformity. There are still several limitations to the present study. First, as a retrospective study, some data were not recorded, such as the ankle joint activity, postoperative satisfaction, and postoperative gait. Second, the decision to operate and intra-operative manipulation were made by distinct surgeons, which creates a possibility for surgeon bias. Third, in this period, there were some cases treated by the physal bar resection and the distal tibial osteotomy simultaneously, but these cases were not included

because we wish to restrict our study to the evaluation of physal bar resection.

Even if the standardized operating techniques are used and appropriate patients are selected, bar resection may fail due to the growth potential of the remaining physis after operation. Our results indicate that with both intraoperative 3D C-arm navigation and traditional X-ray fluoroscopy, bone bridge resection can achieve good results, but there was no significant difference when the results of these two groups were compared. Interestingly, when considering related factors such as surgical history and age, there was also no significant difference in recovery, demonstrating the importance of appropriate case selection and quality of operation technique.

#### Conflict of Interest Statement

The authors have declared that no competing interests exist.

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