OPERATIVE TECHNIQUE

Outcomes of Eight-Plate Epiphysiodesis for Residual Clubfoot Deformities

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Objective: The outcome of congenital clubfoot treatment is still challenging if the feet deformities are not completely corrected. Here we explore a minimal invasive procedure with an eight-plate implant to correct the residual forefoot adduction deformity after treatment of neglected or relapsed clubfoot.

Methods: We retrospectively reviewed patients with residual forefoot adduction deformity after clubfoot treatment between January 2013 and June 2016. The patients underwent temporary epiphysiodesis of the lateral column of the mid-foot, which in detail, an eight-plate was placed on each side of the calcaneocuboid joint. The foot deformities were recorded according to the weight-bearing radiographic measurements including talo-first metatarsal angle, calcaneo-fifth metatarsal angle and medial-to-lateral column length.

Results: A total of 13 patients (20 feet) with an average age of 7.8 years old were located with an average duration of 40.8 months follow-up (range, 28 to 54 months). The average talo-first metatarsal angle improved from 28.3° (range, 19° to 47°) preoperatively to 8.3° (range, 3° to 18°) and the calcaneo-fifth metatarsal angle improved from 29.1° (range, 19° to 40°) preoperatively to 8.4° (range, 0° to 21°) at final follow-up. The mean ratio of the medial-to-lateral column length improved from 1.14 ± 0.06 to 1.55 ± 0.09 with statistical significance ($t = 3.566$; $P < 0.001$).

Conclusions: Eight-plate epiphysiodesis is an easy and effective method for the correction of residual forefoot adduction deformity after clubfoot treatment in growing children without the need of osteotomy.

Key words: Children; Clubfoot deformity; Eight-plate; Epiphysiodesis; Forefoot adduction

Introduction

Congenital clubfoot treatment has been remarkably improved after the appearance of the Ponseti method which was developed in the 20th century by Ignacio Ponseti[1]. Nowadays the method has replaced the surgery and served as the gold standard for the treatment of congenital clubfoot in pediatric orthopedics[2–4]. However, it is still challenging to treat severe cases such as neglected or relapsed clubfoot in older children. Although the Ponseti method, external fixator or extensive open surgery is performed, it always renders some residual deformities such as forefoot adduction, varus, high bow and hindfoot varus and pronation, which are not completely corrected and need further treatment after primary treatment, and the final outcomes might be unsatisfactory in these children[5–8]. Among the deformities, residual forefoot adduction with supination after treatment is a common issue which is also referred to as the "bean-shaped foot"[9]. To the best of our knowledge, the combination of a cuboid closing with a cuneiform opening wedge osteotomy or with a trans-midfoot osteotomy is currently the most popular procedure to correct the residual forefoot adduction[10–14]. However, complications such as neurovascular lesion, non-union or permanent foot stiffness might occur during the operation. In addition, the tarsal growth plate and cartilaginous area could be compromised due to the difficulty in manipulating the osteotomy and fixation process[13].

Temporary epiphysiodesis and hemiepiphysiodesis for growth modulation are established surgical procedures to correct angular deformity in pediatrics which has substantial

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advantages such the reversibility and low operating risk. Eight-plates is one of the major methods that gained popularity quickly due to it allowing temporary growth retardation of the physis without damaging it irreversibly, and is suitable for a variety of indications including different plane deformities around the knee and limb length discrepancies[15]. However, there are few reports regarding eight-plates in individuals with clubfoot deformities.

In this study, we assumed the entire medial and lateral columns of midfoot as two aspects of a long bone metaphysis, we aimed to testify whether the eight-plates technique could restrict the growth of physis of lateral column, and whether it will be of benefit in the management of residual forefoot adduction deformity in growing children.

Methods

Patients' Information

From January 2013 to June 2016, we retrospectively reviewed 13 patients (20 feet) with residual forefoot adduction deformity after clubfoot treatment within 3 years. The inclusion criteria were: (i) the children's age should be from 5 to 10 years old in girls and 5 to 12 years old in boys; (ii) children with clubfoot who still had residual forefoot adduction and supination causing pain associated with shoewear despite previous treatment (the Ponseti method, open surgery or external fixator); (iii) skeletally immature children with open physis at mid-foot and having at least 2 years of growth remaining. (iv) performed with temporary epiphysiodesis operation using eight-plate; and (v) followed up for at least 24 months. In at least 50% of boys, growth plates at mid-foot fusion occur around age 15, whereas in females the growth plate closes about 2 years earlier than in males[16]. We can estimate the closure time of the epiphysis from the patient's age and growth curve.

We excluded patients who had dynamic forefoot adduction or idiopathic metatarsus adductus deformity. The pre- and postoperative radiographic parameters of each enrolled patient was compared separately. The study was approved by the Ethical Committee of Shanghai Sixth People's Hospital (No. 2020-107k), and patients and their guardians gave informed consent.

Preoperative Evaluation

Preoperative evaluation included the presence of deformities, the gait, the range of motion, and the skin condition. Forefoot adduction, supination, and hindfoot varus were also documented qualitatively by visual inspection. In addition, the foot was evaluated for forefoot adduction deformity by Bleck's method assessing the position of the forefoot with respect to the mid-line axis of the hindfoot[11,17].

Preoperative weight-bearing anteroposterior (AP) and lateral X-ray views of ankles and feet were taken for all patients. Main specific parameters measured included the AP talo-first metatarsal angle (TM_1A), the calcaneo-fifth metatarsal angle (CM_5A)[18], the length of the medial and lateral column (Fig. 1)[14]. A medial-lateral column ratio was calculated by dividing the total length of the medial column by the length of the lateral column as measured on each radiograph.[14] On the lateral radiograph, the calcaneo-first metatarsal angle (CM_1A) was measured as an indication of cavus deformities[18].

Surgical Technique

The operation was performed under general anesthesia in supine position. A guidewire was inserted under image intensifier to identify the calcaneocuboid joint space. Then a 2 cm longitudinal lateral incision was made, centered over the calcaneocuboid joint. The periarticular periosteal surface of calcaneus and cuboid was exposed by blunt dissection, taking care not to injure this layer and the perichondrial ring. An eight-plate (Carefix, Shanghai, China) was slipped over the guidewire and transfixed the calcaneocuboid joint with 2 cannulated 3.5 mm screws. Typically, the screw fixed in cuboid was placed just in the center of cuboid so as to block the posterior part of the cuboid physis. A slight overcorrection was accepted for children having long period growth remaining to mitigate the effects of rebound adduction. In addition, in patients nearing skeletal maturity, another small incision over the fifth cubometatarsal joint was performed and two plates

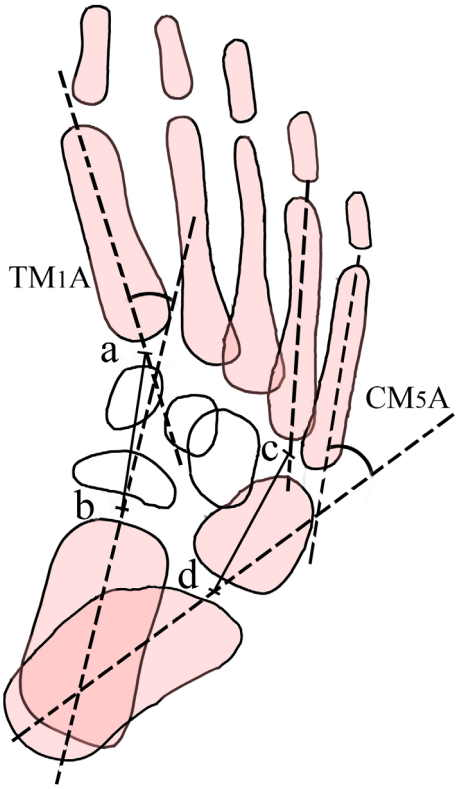

Fig. 1 AP radiographic measurements of forefoot adduction deformity. The medial column length was the distance from the center of the cuneiform-first metatarsal joint (a) to the center of talonavicular joint (b). The length of the lateral column was measured from the center of cuboid-fourth metatarsal joint (c) to the center of the calcaneocuboid joint (d)

were used at both the calcaneocuboid and fifth cubometatarsal joint to expedite the correction.

Postoperative Management

No immobilization was required after surgery, and weight bearing was encouraged from day 1 along with a rapid return to normal activities. Patients were followed up clinically and radiologically at four-monthly intervals, until reaching the neutralization of the axis. Plate removal would not be taken into consideration until skeletal maturity or implants break off. At the final follow-up, postoperative radiographic parameters were compared with preoperative ones. In addition, the residual pain in the feet was evaluated as well.

Statistical Method

All data were explored by SPSS software Version 20 (IBM, Chicago, IL, USA). A paired *t*-test was used to compare the differences between preoperative and postoperative parameters including TM_1A, CM_5A, CM_1A, and medial-to-lateral column length. *P* value <0.05 was considered as significant.

Results

General Results

A total of 13 patients (20 feet) with 7.8 ± 1.6 years old were reviewed with a mean duration of 3 years follow-up (range, 28 to 54 months), and the main specific parameters were measured and recorded (Table 1). According to the skin folds on the inner side of the foot and the skin arcs on the outer edge of the foot, when the foot is in the neutral position, the forefeet were classified by visual inspection postoperatively as having a normal appearance in 17 feet (85%) and mild residual adduction in three feet (15%). Only two patients with two feet reported with slightly residual pain at the final follow-up. Thirteen feet underwent removal of implants without any complications. One patient had one screw broken at 20 months postoperatively, when its correction was achieved.

Radiographic Improvement

The radiographic improvement in different radiological angles confirmed the clinically satisfactory correction in all feet (Table 2, Fig. 2). The average AP TM_1A improved from 28.3° (range, 19° to 47°) preoperatively to 8.3° (range, 3° to 18°), and CM_5A improved from 29.1° (range, 19° to 40°) preoperatively to 8.4° (range, 0° to 21°) in the most recent follow-up. In addition, the mean length of the medial column increased from 3.2 cm (range, 2.5 to 3.8 cm) preoperatively to 5.0 cm (range, 3.7 to 6.0 cm), and the mean cuboid or lateral column length increased from 2.8 cm (range, 2.3 to 3.6 cm) preoperatively to 3.3 cm (range, 2.6 to 3.8 cm). Furthermore, the mean ratio of medial-to-lateral column length improved from 1.14 ± 0.06 to 1.55 ± 0.09 with statistical significance ($t = 20.927$; $P < 0.001$). On the lateral radiograph, the CM_1A was 34.1° (range, 7° to 50°) postoperatively as compared with 42.3° (range, 14° to 63°) preoperatively.

TABLE 1 Characteristics of 13 patients (20 feet) with residual forefoot adduction

					Preoperative				Postoperative				
Case	Age (year)	Sex	Side	Initial previous treatment	TM_1A	CM_5A	CM_1A	M/L	TM_1A	CM_5A	CM_1A	M/L	Follow-up (months)
1	6	F	R	Ponseti	25°	29°	63°	1.24	9°	2°	36°	1.67	49
2	9	M	L	External fixation	30°	37°	46°	1.12	8°	5°	38°	1.55	39
			R	External fixation	29°	33°	43°	1.19	6°	6°	42°	1.63	
3	8	F	R	Ponseti	37°	31°	35°	1.05	13°	10°	37°	1.53	41
4	6	M	L	Open surgery	32°	36°	47°	1.09	9°	13°	46°	1.60	54
5	10	M	L	External fixation	26°	36°	19°	1.16	14°	12°	10°	1.52	38
			R	External fixation	22°	23°	10°	1.12	11°	12°	7°	1.45	
6	9	F	R	Open surgery	29°	32°	35°	1.13	7°	18°	35°	1.47	35
7	5	M	L	External fixation	21°	20°	43°	1.08	5°	0°	32°	1.42	52
			R	External fixation	25°	19°	40°	1.14	6°	2°	30°	1.40	
8	8	M	L	Ponseti	26°	31°	30°	1.10	7°	4°	37°	1.59	37
			R	Ponseti	29°	37°	45°	1.05	7°	21°	40°	1.53	
9	10	M	R	Ponseti	30°	26°	23°	1.06	9°	11°	25°	1.39	28
10	9	F	L	External fixation	33°	31°	32°	1.19	18°	14°	35°	1.47	34
11	7	F	L	Ponseti	26°	26°	34°	1.16	5°	2°	39°	1.65	46
			R	Ponseti	28°	26°	38°	1.10	7°	5°	35°	1.58	
12	6	M	L	Open surgery	25°	21°	40°	1.21	4°	3°	39°	1.63	41
			R	Ponseti	19°	22°	36°	1.24	3°	7°	34°	1.55	
13	8	M	L	Open surgery	27°	25°	32°	1.21	7°	4°	35°	1.64	37
			R	External fixation	47°	40°	56°	1.09	10°	17°	50°	1.68	

Abbreviations: CM_1A, calcaneo-first metatarsal angle; CM_5A, calcaneo-fifth metatarsal angle; M/L, medial-lateral column ratio; Postoperative, the time is at final follow-up; TM_1A, talo-first metatarsal angle.

TABLE 2 Pre- and postoperative radiographic measurements

Radiographic parameters	Preoperative		Postoperative		Average improvement	*t*, *P* value
	Average	Range	Average	Range		
AP TM_1A	28.3°	19°–47°	8.3°	3°–18°	20.0°	16.53, <0.001
AP CM_5A	29.1°	19°–40°	8.4°	0°–21°	20.7°	17.31, <0.001
Lateral CM_1A	37.4°	10°–63°	34.1°	7°–50°	3.3°	1.94, 0.0678
M/L	1.14	1.05–1.24	1.55	1.39–1.68	0.41	20.93, <0.001

Abbreviations: AP, anteroposterior; CM_1A, calcaneo-first metatarsal angle; CM_5A, calcaneo-fifth metatarsal angle; M/L, medial-lateral column ratio; Postoperative, the time is at final follow-up; TM_1A, talo-first metatarsal angle.

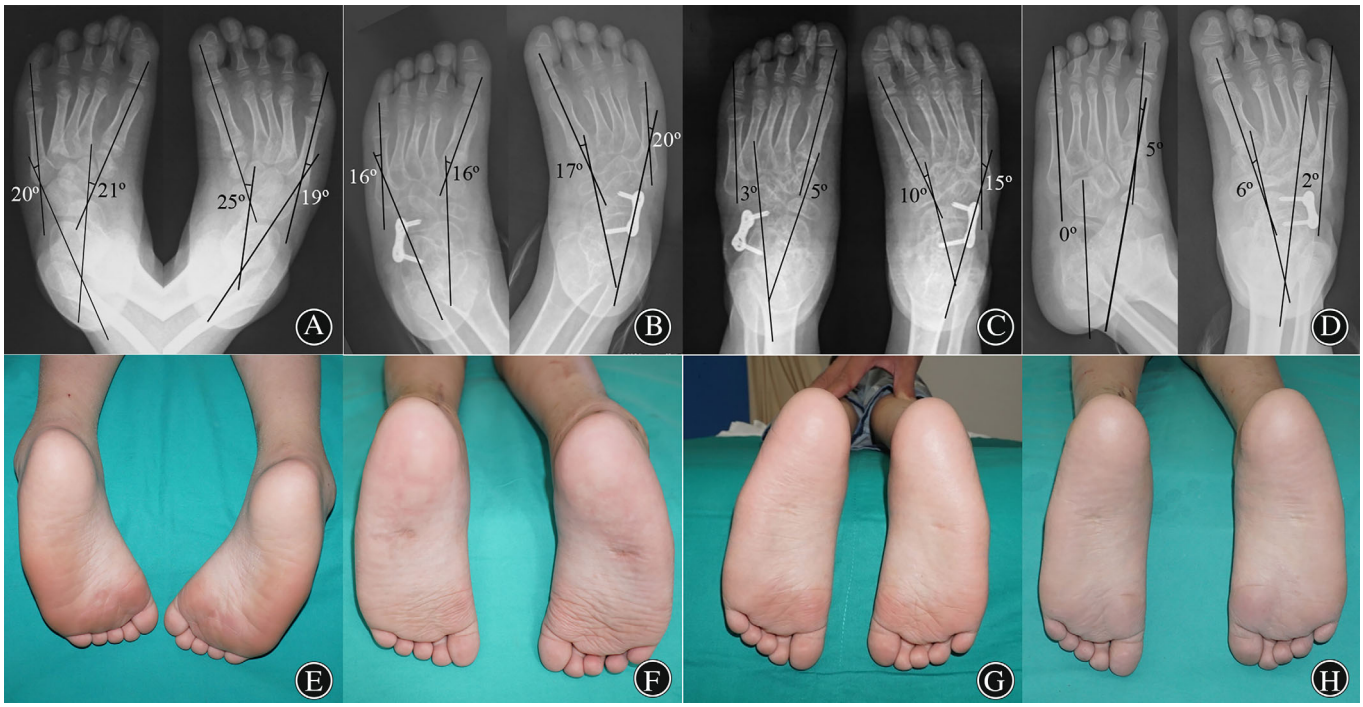

Fig. 2 Gradual correction of deformities could be achieved with eight-plate epiphysiodesis. (A, E) AP radiograph and the appearance of the feet before treatment in a boy aged 9 years with bilateral forefoot adductions. (B, F) One year postoperative, partial correction of both feet. (C, G) Two years postoperative, left foot was well corrected and right foot was still mild adducent. (D, H) After 4-year follow-up, complete correction of the right foot was achieved and correction of the left foot was well maintained

Discussion

In this study, we performed a temporary epiphysiodesis through transfixing the calcaneocuboid joint or both the calcaneocuboid and fifth cubometatarsal with the eight-plate due to the fact that the children have potential growth with developing medial cuneiform and navicular ossific nucleus. The clinical outcomes showed that gradual correction of forefoot adduction deformity was achieved with the foot grew. The degrees of adduction correction obtained by eight-plate, according to the measurement of TM_1A (20.0°) and CM_5A (20.5°), which were comparable to other reports with the osteotomy procedures[13,14]. Moreover, the assessment of pre- and postoperative medial-to-lateral column ratio confirmed that the procedure improved the proportionate length of the columns. These outcomes manifested the successful correction of residual forefoot adduction deformity after clubfoot treatment.

Difficulties in Forefoot Adduction Deformities Treatment

The forefoot adduction deformities could cause shoewear problems and functional limitations that disturb gait and daily activities. The physiopathology of forefoot adduction attributes to the imbalance between the elongated lateral

column and shortened medial column of the midfoot. Hence many types of osteotomies have been attempted which require internal or external fixation and restricted weight bearing[10–14]. However, the bony deformity in children could also be corrected by manipulating the growth behavior of an open physis. Guided growth for angular correction was first introduced by Stevens when he reported on the use of hemiepiphysiodesis with tension band plating technique to correct deformities in growing children[19], and it has become a mature method to correct frontal plane deformities around the knee in many studies[20–22].

A cavus deformity of the foot is sometimes easily recognizable and flexible. However, if the patient is left untreated, it would become a fixed bony deformity. The treatment goals of cavus are to achieve a stable, pain-free and motor-balanced foot[23]. In this study, we measured CM_1A as an indicator of the cavus deformities, and the results showed the improvement in cavus from 42.3° preoperatively to 34.1° postoperatively, suggesting the length restoration of the medial column could lead to the correction of the cavus deformity. The traditional surgical options mainly consist of soft-tissue releases for a flexible deformity while osteotomy for a fixed deformity. However, we believe that a temporary epiphysiodesis could also improve the cavus deformity with the influence on bone growth modulation in children.

Surgical Tips of Eight-Plate Fixation

The fixation in a small partially ossified cuboid is technically difficult, and we found that the cuboid usually does not have sufficient ossified place for 3.5 mm screw fixation until age 5. Anderson *et al.* reported that the foot grows at an average of 0.9 cm per year between 5 and 12 years of age in girls and between 5 and 14 years of age in boys[24]. Therefore, we believe this procedure is suitable for children between 5 and 10 years of age with moderate-to-severe fixed (rigid) forefoot adduction deformity. However, it is still challenging to choose the optimal timing of surgery for children nearing maturity. Here we found that two plates transfixing both the calcaneocuboid and fifth cubometatarsal joint could provide a faster rate of deformity correction in older children.

There are some shortcomings of eight-plate epiphysiodesis compared to osteotomies. For example, limited by the rate of the foot growth, eight-plate epiphysiodesis cannot correct severe forefoot adduction, which is age-sensitive that the residual deformities may occur in children approaching maturity, just as the mild residual adduction in three feet reported in this study. Common complications of eight-plate epiphysiodesis are wound infection, swelling, joint stiffness, screw loosening and screw breakage. However, because osteotomies are more invasive, these complications may also occur after osteotomies and are more common[25]. Under the condition that there is sufficient growth remaining, the absolute advantage of eight-plate epiphysiodesis lies in the minimal invasive procedure whereby only a small lateral incision was made for inserting an eight-plate without impairing the mobility of foot.

Moreover, we believe that early weight wearing and gradual correction could bring a new geared intertarsal joint without stiffness. In the process, due to the constant adjustment of extrinsic muscles, the arch of the foot remains stable. In addition, eight-plate epiphysiodesis causes minimal disturbance to the medial column growth plate which avoids the complex alignment procedures and the process is reversible. Therefore, the result in our study is predictable, associated with early mobilization, less recovery time and low costs which makes eight-plate implant the first option for forefoot adductive corrections while the physis is still open.

Limitations of the Study

The limitations in this study include the small number of patients and the short duration of follow-up with an average 40.8 months. We were unable to evaluate the rebound growth due to insufficient follow-up data until skeletal maturity, and a long-term outcome of this procedure is still needed. However, since it is a simple and well tolerated procedure, it would not preclude other types of treatment once rebound occurs. Meanwhile, although previous studies have shown that the talo-first metatarsal angle used to describe the forefoot adduction correlated significantly with the clinical score of Pirani clinical scoring system[26], there was no preoperative or postoperative evaluation of foot function. In subsequent studies, it is necessary to increase the sample size, extend the follow-up time and develop a more perfect evaluation system.

Conclusions

Eight-plate epiphysiodesis is an effective and predictable method for the correction of residual forefoot adduction deformity after clubfoot treatment. We believe that this procedure is useful for children between 5 and 10 years of age that still have potential growth with developing ossification center, and should be served as an alternative method to osteotomies.

Author Contributions

Haoyu Zhao: conceptualization, data collection. Hongjiang Ruan: data collection, manuscript writing. Yuting Cao: statistical analysis, manuscript editing. Hengfeng Yuan: supervision, manuscript revision. Qinglin Kang: patients' treatments, supervision, and final approvement of submission. All authors read and approved the manuscript.

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