

# Anterior distal tibial hemi-epiphysiodesis for the treatment of fixed equinus in patients with recurrent clubfoot and sufficient growth potential

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The management of recurrent clubfoot (RCF) in children of walking age is challenging, especially when secondary anatomic changes such as talar flattening are present. The purpose of this study was to report our experience with the use of anterior distal tibial hemi-epiphysiodesis (ADTH) in children with RCF and fixed equinus, to evaluate clinical and radiographic outcomes, and to compare our results with the available literature. This is a retrospective review of 14 patients (20 distal tibiae) treated with ADTH at our pediatric orthopedics referral institution between September 2021 and November 2022. The mean age at surgery was 10.1 years, and the mean follow-up was 23.7 months. Preoperative anterior-posterior (AP) and lateral radiographs and annual postoperative AP and lateral weight-bearing radiographs were reviewed to assess anterior distal tibial angle (ADTA), screw spread angle (SSA), and the correlation between SSA and ADTA variation. Clinical assessment was performed by measuring maximum ankle dorsiflexion and using the AOFAS scale. Complications were also recorded. Preoperative mean dorsiflexion was  $-7.1 \pm 7.5^\circ$  with negative values indicating plantarflexion. At final follow-up, mean dorsiflexion was  $1.8 \pm 8.2^\circ$ , with a statistically

significant mean correction rate of  $8.9 \pm 11.14^\circ$ . Final ADTA and SSA showed  $12.8 \pm 8.4^\circ$  ( $P < 0.001$ ) and  $20.8 \pm 16.9^\circ$  ( $P < 0.005$ ) of improvement, respectively. There was also a good correlation ( $r = 0.642$ ) between the change in SSA and the change in ADTA. Plate and screws were removed in 1/20 cases (5%). ADTH in patients with RCF and fixed equinus reduces pain, minimizes equinus, and improves SSA and ADTA with limited complications. *J Pediatr Orthop B XXX: XXXX-XXXX* Copyright © 2025 Wolters Kluwer Health, Inc. All rights reserved.

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## Introduction

Recurrent clubfoot (RCF) is defined by the recurrence of any or all components of the original deformity after successful treatment. Although it can occur at any time up to skeletal maturity, it is more common in the 1<sup>st</sup> and 2<sup>nd</sup> years after completion of treatment and is more often secondary to noncompliance with bracing [1–3].

The management of RCF in children of walking age is challenging, especially in the presence of secondary anatomic changes such as talar flattening (TF), which further limits ankle dorsiflexion and contributes to fixed equinus [4,5]. TF was first described in 1962 and later classified in 1974 based on the severity of the change in talar dome morphology [5,6], and although there is no consensus on its causes, such deformity has been observed following surgical and nonsurgical treatment of both idiopathic and nonidiopathic clubfoot. However, it has been shown that loss of talar dome sphericity reduces ankle dorsiflexion and can result in

fixed equinus due to anterior impingement with the distal tibia, leading to ankle pain in childhood and the development of osteoarthritis (OA) in early adulthood [7].

Surgical treatment of RCF, including equinus deformity, includes gastrosoleus complex lengthening, posterior release, or supramalleolar osteotomy and correction with a ringed external fixator when the use of less invasive approaches is limited due to the presence of significant morpho-anatomic changes of the ankle [8,9]. As an alternative to the previous techniques, anterior distal tibial hemi-epiphysiodesis (ADTH) was first reported in 2011 as a safe and effective method to correct equinus in selected patients with RCF [10]. In fact, the same technique was previously proposed by Kramer and Stevens in 2001 for guided growth to correct knee flexion contractures in patients with sufficient residual growth [11]. Based on this concept, some authors proposed guided growth by tethering the anterior distal tibial physis to

achieve gradual correction of equinus in children with RCF and sufficient growth potential [10,12].

The purpose of this study was to report our experience with the use of ADTH in children with RCF and fixed equinus, to evaluate the clinical and radiographic outcomes of these patients, and to compare our results with the few other studies published in the literature.

## Methods

### Study design

This is a retrospective review of 14 consecutive patients (nine males and five females) with idiopathic RCF and fixed equinus who were treated with ADTH at our pediatric orthopedics referral Institution between September 2021 and November 2022.

Initial treatment was performed using the Ponseti technique by the same surgeon who managed the patients and later performed the ADTH.

The mean age at initial treatment was 3 weeks (range: 2–4), and the mean Dimeglio and Pirani scores were 14 (range: 10–18) and 3.5 (range: 2.5–5.5), respectively. The mean number of casts per patient was 4 (range: 3–6). All patients developed RCF with associated TF or dysmorphic changes of the talar neck, resulting in fixed equinus.

Equinus deformity was defined as the inability to dorsiflex the ankle beyond neutral with the knee extended. Specifically, the parameters used to define fixed equinus for the purposes of this study were:

1. Angle of ankle dorsiflexion  $\leq 0^\circ$  measured passively with a goniometer with the knee extended and flexed [13].
2. Distance measured by the knee-to-wall test (to assess active ankle dorsiflexion)  $\leq 6$  cm [14].

Table 1 summarizes the demographic and treatment details of the patients.

During the study period, a total of 20 distal tibiae underwent ADTH (six bilateral and eight unilateral cases; 12 right and eight left). The mean age at surgery was 10.1 years (range: 7.5–12.9), and the mean follow-up was 23.7 months (range: 18–34). In addition to ADTH, the following procedures were performed in eight patients ( $n = 8$  distal tibia;  $n = 11$  concomitant procedures) Achilles tendon lengthening ( $n = 4$ ; 36.4%), medial Cotton's osteotomy ( $n = 3$ ; 27.2%), cuboid closing wedge osteotomy ( $n = 3$ ; 27.2%), and tibialis anterior tendon transfer ( $n = 1$ ; 9%).

### Surgical technique and postoperative protocol

The surgery was performed under general anesthesia with the patient in the supine position on a radiolucent table with a tourniquet applied.

The distal tibia was exposed through an anterior approach with a 3 to 4 cm longitudinal incision, and the interval

**Table 1 Demographics and treatment details**

Demographics	
Age, year (mean, range)	10.1 (7.5–12.9)
Sex, $n$ (%)	
Male	9 (64.3)
Female	5 (35.7)
Treatment details	
Laterality, $n$ (%)	
Right	12 (60)
Left	8 (40)
Severity (mean preoperative AOFAS score)	65/100
Other associated procedures	
Tot = 11 ankles (11/20 = 55%)	
Achilles tendon lengthening	4/11 (36.4%)
Medial cuneiform Cotton's osteotomy	3/11 (27.2%)
Cuboid closing wedge osteotomy	3/11 (27.2%)
Tibialis anterior tendon transfer	1/11 (9%)
Complications, $n$ (%)	
Eight-plate displacement	1 (5)
Superficial wound dehiscence	1 (5)
Pain	0 (0)
Infection	0 (0)

AOFAS, American Orthopedic Foot and Ankle Society.

between the tibialis anterior and the extensor hallucis longus was developed. A Kirschner wire was placed under fluoroscopy in the middle of the anterior part of the distal tibial physis, and the plate was fixed with two cannulated screws. The length of the screws was selected to be 1/3 to 1/2 of the length of the distal tibial physis in lateral view. Figure 1 describes the details of the surgical technique.

After surgery, patients were allowed to bear full weight and began early range-of-motion exercises as tolerated.

All surgical procedures were performed by a senior surgeon with more than 15 years of experience in foot surgery. This surgeon undertook the clinical assessment and made the decision to perform surgery.

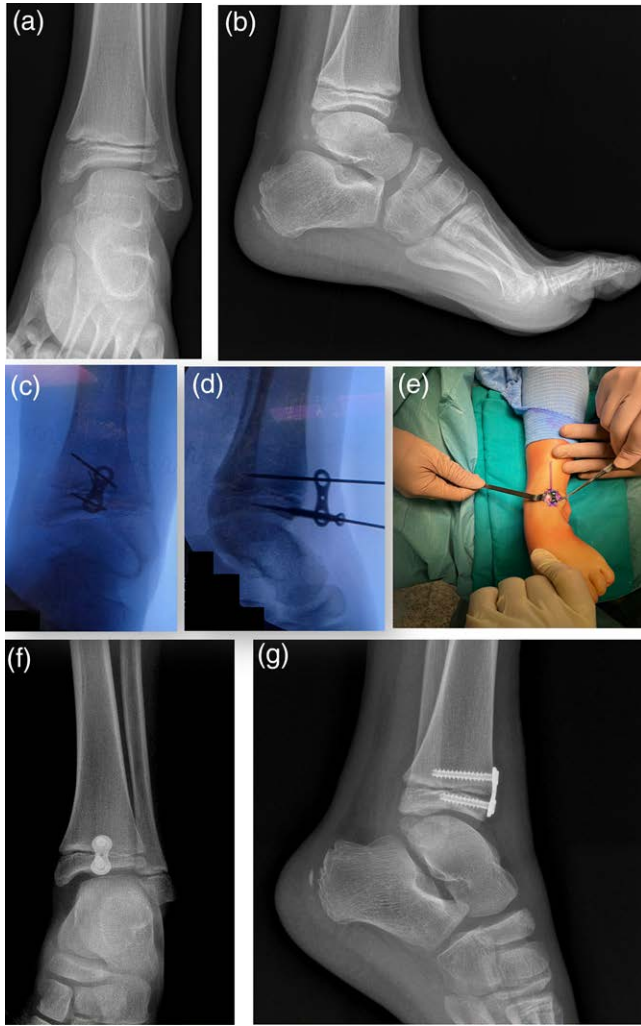
### Radiographic assessment

Preoperative anterior-posterior (AP) and lateral radiographs and annual postoperative AP and lateral weight-bearing radiographs were reviewed to evaluate the following parameters:

1. Anterior distal tibial angle (ADTA) measured on lateral radiographs as the angle formed between the anatomical axis of the tibia and the joint line [10] (Fig. 2).
2. Screw spread angle (SSA) measured on lateral ankle radiographs as the divergence between the long axis of the screws [3].
3. Finally, we examined the potential correlation between SSA and ADTA variation.

An experienced pediatric orthopedic surgeon with more than 15 years of experience (SM) performed all radiographic measurements and evaluations using our institution's picture archiving and communication system (GE Healthcare, Chicago, Illinois, USA) to avoid inter- and intra-observer error.

Fig. 1



Boy, 10.2 years of age: (a, b) preoperative anterior-posterior and lateral radiographs; (c, d) intraoperative fluoroscopic images; (e) final positioning and fixation of the eight-plate on the distal tibia; (f, g) postoperative anterior-posterior and lateral radiographs.

### Clinical evaluation

All patients underwent preoperative and postoperative clinical evaluation. Postoperative follow-up visits were scheduled every 6 months.

Global clinical assessment was performed by measuring maximum ankle dorsiflexion and using the American Orthopedic Foot and Ankle Society (AOFAS) scale, which consists of a nine-point scoring system divided into three domains: pain (40 points), functional appearance (50 points), and alignment (10 points), for a total amount of maximum 100 points [15]. Specifically, pain was assessed at each clinical visit, and a pain score (maximum of 40 points) was recorded.

### Statistical analysis

Statistical analysis was performed with SPSS 22.0 (SPSS, Chicago, Illinois, USA). Data are presented as means and

Fig. 2



ADTA measurement on lateral radiographs. ADTA, anterior distal tibial angle.

standard deviations. Student's *t*-test was used to compare preoperative and final follow-up radiographic and clinical results. The correlation between the changes in SSA and the changes in ADTA was assessed using a scatterplot and a linear fit was performed. The *r* parameter was also calculated.  $P < 0.01$  was considered statistically significant.

## Results

### Radiographic assessment

At final follow-up, ADTA and SSA showed  $12.8 \pm 8.4^\circ$  ( $P < 0.001$ ) and  $20.8 \pm 16.9^\circ$  ( $P < 0.005$ ) of improvement, respectively (Table 2).

Radiographic improvements of ADTA and SSA in two patients are shown in Figs. 3 and 4.

There was also a good correlation ( $r = 0.642$ ) between the change in SSA and the change in ADTA (Fig. 5).

### Clinical evaluation

The mean preoperative dorsiflexion was  $-7.1 \pm 7.5^\circ$  (range:  $-20-0^\circ$ ), with negative values indicating plantar flexion. At the final follow-up, the mean dorsiflexion was  $1.8 \pm 8.2^\circ$  (range:  $-10-15^\circ$ ), showing a mean correction rate of  $8.9 \pm 11.14^\circ$ , which was statistically significant ( $P = 0.003$ ).

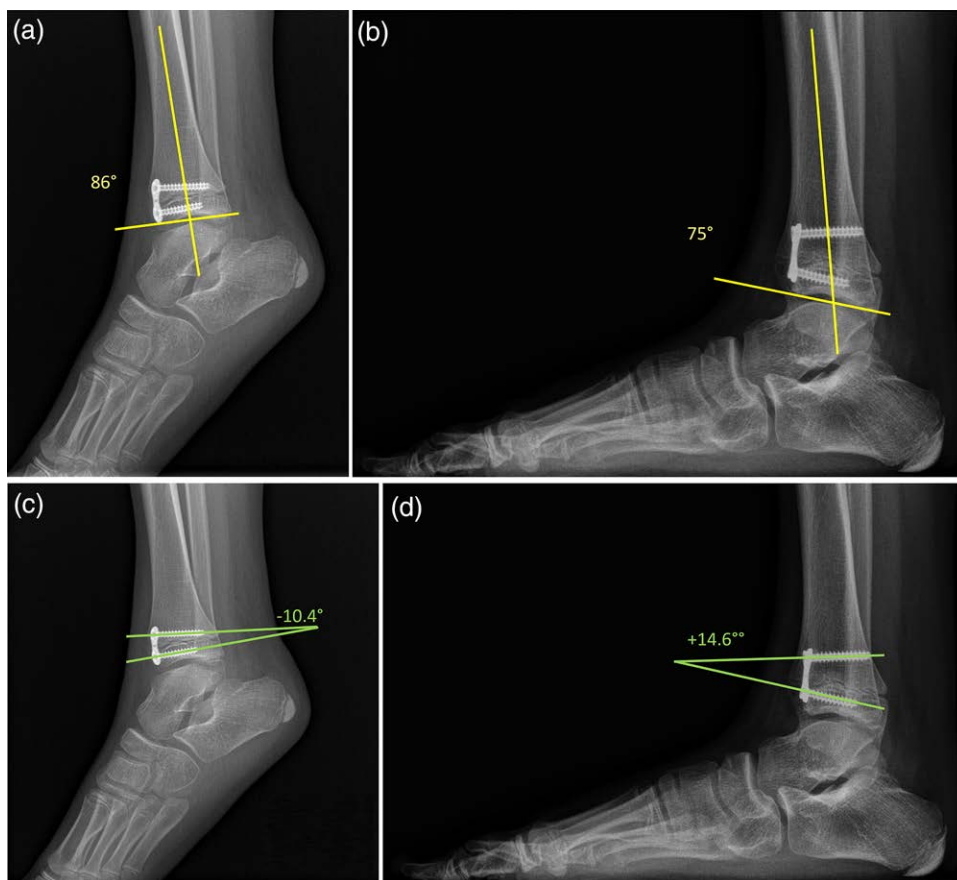
The mean increase in AOFAS score at the final follow-up was  $26.9 \pm 9.8$  points (range: 54–79 preoperatively and 65–100 postoperatively) ( $P \leq 0.007$ ) (Table 3).

**Table 2 Mean radiographic and clinical changes following anterior distal tibial hemi-epiphysiodesis**

Mean ± SD, range				
Parameter	Average preoperative value	Average final value	Average delta	P-value
Maximum ankle dorsiflexion	-7.1 ± 7.5° (-20-0°)	+1.8 ± 8.2° (-10-+15°)	8.9 ± 11.4°	0.003
Radiographic ADTA	86.35 ± 3.82° (80-95°)	73.55 ± 7.45° (60-84°)	12.8 ± 8.4°	0.01 × 10 <sup>-5</sup>
Radiographic SSA	-3.5 ± 7.8° (-16- +8°)	+17.3 ± 14.9° (-12- +46°)	20.8 ± 16.9°	0.05 × 10 <sup>-4</sup>

ADTA, anterior distal tibial angle; SSA, screw spread angle.

**Fig. 3**



Girl, 7.11 years: (a, b) radiographic changes in ADTA and (c, d) radiographic changes in SSA at 22 months follow-up. ADTA, anterior distal tibial angle; SSA, screw spread angle.

Specifically, when considering the pain portion of the AOFAS score (maximum 40 points), the mean increase was 12.1 ± 7.0 (*P* < 0.006).

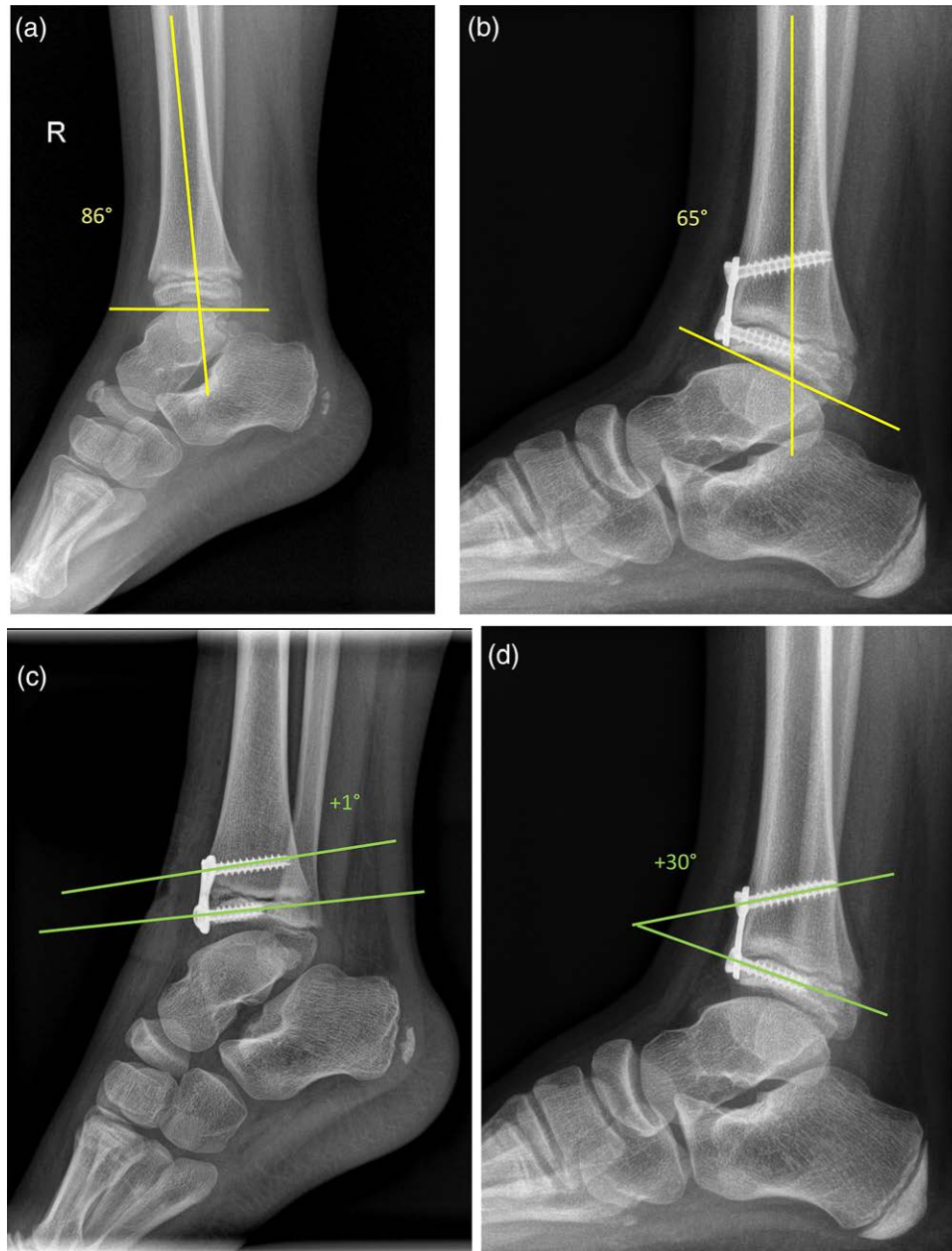
Two out of 20 ADTHs (10%) experienced complications: a superficial wound dehiscence that resolved within 2 weeks, and a secondary displacement of the eight-plate. The secondary proximal displacement of the eight-plate occurred in a patient who underwent bilateral ADTH; in this case, 2 years after the surgical intervention, X-rays showed proximal displacement of the eight-plate on the left side. The plate and screws were then removed and repositioned; the patient's outcome is yet to be determined due to the limited

follow-up period. No recurrence of deformity was observed.

**Discussion**

The results of the present study highlight that ADTH is a safe and effective method for the treatment of RCF and fixed equinus in children with sufficient growth potential, as evidenced by the presence of radiographic and clinical improvements consistent with the literature [3,12,13]. Specifically, improvements in ankle dorsiflexion, ADTA, and SSA were observed and were associated with a reduction in pain due to anterior impingement between the flattened talus and distal tibial epiphysis.

Fig. 4



Girl, 7.9 years: (a, b) radiographic changes of ADTA and (c, d) radiographic changes of SSA after a follow-up of 26 months. ADTA, anterior distal tibial angle; SSA, screw spread angle.

ADTH was first described in 2011 by Al-Aubaidi *et al.* [10], who reported poor clinical outcomes with a mean improvement of 2° in ankle dorsiflexion despite significant variability in ADTA (mean correction of 15°) in a cohort of 31 ankles followed for a mean of 22 months.

One factor that may have influenced this difference between the results of Al-Aubaidi and the present study is the mean age at surgery, which was 10.1 years in our population and 6.9 years in the Al-Aubaidi *et al.* study [10]. Such a difference may be explained by the fact that

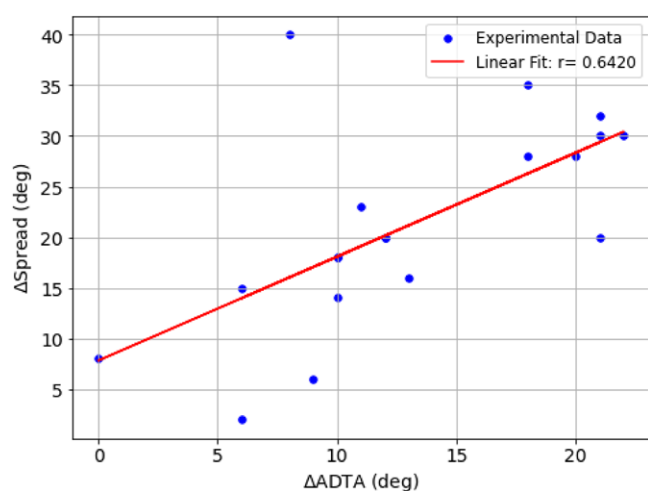
performing the same procedure in older patients during a period of accelerated growth results in a more rapid correction.

Consistent with our findings, a more significant increase in ankle dorsiflexion was observed in other studies using population samples comparable to ours in terms of sample size, mean age at surgery, and mean follow-up. In particular, Ebert *et al.* [13] published similar results in a sample of 23 ankles with a mean age at surgery of 11.3 years and a follow-up period comparable to the present

study. Both studies by Zargarbashi *et al.* [12] and Ebert *et al.* [13] showed a statistically significant improvement in ADTA and ankle dorsiflexion, which is consistent with our results.

Paley first mentioned the ADTA, stating that the correct value was 79.8 ° [16]. This angle was subsequently investigated further. In 2006, Magerkurth found that the average ADTA value was 83 °, ranging from 76 to 97 ° [17]. Another study published in 2022 reported that the normal range for ADTA is 80 ± 2 °. In literature, deviations from the normal values of ADTA that exceed 5 ° are generally considered sagittal plane misalignments [18]. Although understanding ankle biomechanics remains elusive due to the joint’s complexity, the literature suggests that a nonphysiological ADTA can lead to overload, pain, and OA [19]. There is a lack of studies on this topic in pediatric populations, and the possible consequences of ADTA change are uncertain. Although overcorrecting the tibial slope could potentially impact long-term outcomes due to altered ankle kinetics, the ankles in our study were already significantly altered by a fixed equinus deformity associated with TF. This deformity itself can be an important risk factor for OA development. As in previous studies [3,12,13], ADTH alleviated pain and enabled patients to walk and perform daily activities.

Fig. 5



Change in ADTA vs. change in SSA. ADTA, anterior distal tibial angle; SSA, screw spread angle.

Measurement of SSA was first reported by Giertych *et al.*, who showed a significant increase in screw divergence over a 34-month follow-up period. The present study examined the changes in SSA, which showed significant variation consistent with the work of Giertych *et al.* [3]. Furthermore, a good correlation was found between the variation of ADTA and SSA ( $r = 0.642$ ; Fig. 5). Our results are in agreement with previously published results (Table 4).

In 1/20 cases (5%), the plate and screws were removed due to secondary displacement; in this case, the plate and screws were repositioned. No recurrence of deformity was observed.

However, a longer follow-up and a larger sample size may be useful to obtain more precise information about a possible correlation between age at surgery and correction progress over time.

Complications encountered in our cohort of patients have already been reported in the literature, including hardware-related skin irritation, wound dehiscence, wound infection, and screw loosening or fracture [20,21].

The secondary proximal displacement of the eight-plate after 2 years was probably due to the distal screw being initially positioned too close to the physis.

This study provides a comprehensive overview of pre- and postoperative clinical, functional, and radiographic outcomes of ADTH in children with RCF and fixed equinus, with a mean follow-up of 2 years.

The study has several limitations, including its retrospective design, small sample size, and relatively short follow-up period. Despite these limitations, however, the results are comparable to those initially reported by Giertych *et al.* [3]. Although long-term results are not yet available, the trend is promising.

In conclusion, ADTH in patients with RCF and fixed equinus results in improved apparent ankle dorsiflexion, SSA, and ADTA, as well as a temporary reduction in pain over the first 2 years. This procedure is a safe and effective option for these patients with few complications, consistent with previous published results [3]. Further studies are needed to validate these preliminary results.

In particular, longer follow-up periods and larger sample sizes are needed to investigate the possible correlation between age at surgery and correction progression over

Table 3 Improvement of clinical outcome (American Orthopedic Foot and Ankle Society)

	Mean ± SD			P value
	Preoperative	Follow-up	Average delta	
AOFAS total score	65 ± 4.2 (54–79)	92 ± 8.8 (65–100)	26.9 ± 9.8	0.07 × 10 <sup>-10</sup>
AOFAS pain score	25 ± 5 (20–30)	37.1 ± 4.7 (30–40)	12.1 ± 7.0	0.06 × 10 <sup>-5</sup>

AOFAS, American Orthopedic Foot and Ankle Society.

Table 4 Comparison between results of the present study and available literature

	Mean age		Maximum ankle dorsiflexion			Radiographic ADTA			Radiographic screw spread angle		
	at surgery (years)	Mean FU (months)	Preop	Postop	$\Delta$ , P value	Preop	Postop	$\Delta$ , P value	Preop	Postop	$\Delta$ , P value
Al-Aubaidi et al. (2011) [10] 31 ankles	6.9	22	2.4 °	5.16 °	>0.05	85.4 °	70 °	<0.01	n/a	n/a	n/a
Zargarbashi et al. (2019) [12] nine ankles	7.3	14.1	-27.7 ± 9.3 °	-2.2 ± 14.6 °	<0.01	86.3 ± 2.4 °	69 ± 3.5 °	<0.01	n/a	n/a	n/a
Ebert et al. (2020) [13] 23 ankles	11.3	20.3	-3.3 °	6.1 °	<0.01	87.5 °	75.8 °	<0.01	n/a	n/a	n/a
Giertych et al. (2022) [3] 20 ankles	10	34	-5.7 ± 10.7 °	+2.7 ± 9.7 °	0.059	87.7 ± 5.7 °	69.8 ± 13.8 °	<0.05	1.5 ± 4.2 °	30.7 ± 14.3 °	n/a
This study (2025) 20 ankles	10.1	23.7	-7.1 ± 7.5 °	+1.8 ± 8.2 °	<0.01	86.35 ± 3.82 °	73.55 ± 7.45 °	<0.001	-3.5 ± 7.8 °	+17.3 ± 14.9 °	<0.001

ADTA, anterior distal tibial angle.

time. This will help us determine if increasing the ADTA can lead to significant TF correction. It will also help us determine if other symptoms or early OA develop following the change in load distribution due to the ADTA modification.

## Acknowledgements

### Conflicts of interest

There are no conflicts of interest.

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