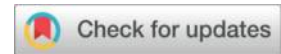




Study on the influence of Ponseti method on the development of children's clubfoot and its strategies



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Abstract: Congenital clubfoot is one of the most common lower limb musculoskeletal system malformations in children's orthopedics, mainly manifested as hind foot clubfoot, varus, middle foot high arch and forefoot adduction malformations. According to the relevant data of the World Health Organization (WHO), about 130,000 newborns worldwide suffer from clubfoot every year, and the incidence rate is about 0.3‰-7.8‰, which varies in different ethnic groups. According to the pathogenesis, it can be roughly divided into idiopathic clubfoot or clubfoot with multiple joint contracture, spina bifida or myelomeningocele and other abnormalities. In the past few decades, the treatment of clubfoot has gradually changed from traditional surgical treatment (posterolateral soft tissue release, posterolateral soft tissue release, etc.) to non-surgical treatment based on Ponseti method, and a large number of studies have reported its good long-term clinical follow-up effect. In this paper, the influence factors of Ponseti method on the foot development of children with equine varus foot were analyzed and studied.

Key words: Ponseti; Horseshoe varus; Children; Foot development

1. Research background

After using the Ponseti series of techniques and plaster casting, the appearance and function of the ankle in most children with clubfoot are almost entirely normal. However, there is still much debate regarding whether the imaging indicators of the affected foot have recovered after correction. In our previous study, which followed up for an average of 4.8 years, we found that compared to the normal side, the neutral plantar angle, lateral plantar angle, and the distance-to-heel index of the affected foot decreased. The first metatarsal angle of the lateral talus also decreased, while the fifth metatarsal angle of the calcaneus increased. The angles of the first and fifth metatarsals on the lateral side also increased, while those of the first metatarsal in the neutral position and the fifth metatarsal of the calcaneus decreased. These results indicate that after treating clubfoot with the Ponseti method, there is residual mild inversion deformity of the hindfoot and adduction deformity of the forefoot, but high-arch deformity has been completely corrected. The maximum diameter measurements of the ossification centers of the tarsal and metatarsal bones showed that the ossification centers of the affected side were smaller compared to the normal side, with statistically significant differences, indicating delayed development of the tarsal bones in clubfoot. The maximum diameter measurements of the ossification centers of the metatarsals showed that, except

for the fourth and fifth metatarsals, the ossification centers of other metatarsals were smaller on the affected side, with statistically significant differences. This suggests delayed development of the medial metatarsal in clubfoot, while the lateral fibular metatarsal developed normally. This indicates that from a developmental perspective, clubfoot has a tendency towards persistent deformity recurrence.

Researching and mastering the ossification process of the tarsal bones in idiopathic equinus and the development of the foot is crucial for successfully completing the Ponseti method treatment, maintaining its effectiveness, and preventing recurrence. Therefore, our research group conducted a retrospective study on idiopathic equinus at our center to explore the impact of Ponseti method treatment on the development of the talus, navicular bone, and foot length and width in children, as well as its effects on ankle dorsiflexion function and final follow-up outcomes.

2. Materials and methods

2.1 Selection of research subjects

A retrospective analysis was conducted on the database of children with clubfoot who received continuous treatment and follow-up visits from October 2007 to December 2013 at our hospital and the Yinghua Pediatric Orthopedic Group. All patients were treated by the same orthopedic physician using standard Ponseti methods. The study protocol was approved by the Ethics Committee of Xinhua Hospital affiliated with Shanghai Jiao Tong University School of Medicine

The criteria for inclusion are as follows:

- (1) Idiopathic equinus;
- (2) The initial age of the child is less than 2 years old;
- (3) Complete the recommended Ponseti treatment regimen, and follow up age is not less than 5 years old;
- (4) No history of previous treatment.

Exclusion criteria are as follows:

- (1) Other types of clubfoot, such as postural type, neuromuscular type, multi-joint contracture, syndrome type, combined limb dysplasia, etc.;
- (2) Children who have been treated before admission, including non-surgical treatment and surgical treatment;
- (3) The age of the child is more than 2 years old;
- (4) Currently still under treatment, the follow-up age is less than 5 years old, and the case brace is worn for less than 1 year after recurrence treatment;
- (5) The patient's data are missing or the X-ray of the foot and ankle is not in the correct position;
- (6) Not signing an informed consent or unwilling to participate in the study protocol;

2.2 Grouping of research subjects

2.2.1 Analysis of the effect and prognosis of Ponseti method on the measurement and development of foot in talipes varum

- (1) A comparative study on the development of feet of children with clubfoot treated by Ponseti method at different ages

According to the initial age of admission in this study, the children were divided into three groups:

Group I (0 to 1 month), Group II (1 to 3 months), and Group III (3 to 2 years);

- (2) Study on the effect of Ponseti method on talus development in equinovarus: R/L ratio and α Angle
- (3) Study on the effect of Ponseti method on the development of navicular bone in talipes eversion
- (4) Study on the effect of Ponseti method on the development and size of foot appearance in talipes valgus;

Long feet, wide front feet, wide back feet;

2.2.2 The effect of foot measurement on the development after Ponseti treatment on the final evaluation results of follow-up

- (1) The effect of foot measurement on the development of ankle dorsiflexion function at the end of follow-up
- (2) Risk factors for the study of foot development on the International Study Group of Horseshoe Inversion

2.3 Measurement of foot development in children with idiopathic equinus ——— X-ray imaging

2.3.1 Standard photographic position

Common radiographic views used for the ankle and foot include anteroposterior and lateral views of the ankle joint, anteroposterior and oblique views of the dorsum of the foot, anteroposterior and lateral views of the foot, and axial views of the calcaneus. The most commonly used view for measuring equinus deformity is the anteroposterior view of the foot. The evaluation and measurement of radiographic results depend crucially on the position taken during imaging. A standard, unbiased, and clear X-ray is essential for accurate assessment and measurement. Therefore, evaluating the developmental status of children with equinus deformity must start from a standardized imaging position. According to literature reports[1], for anteroposterior foot radiography, the ankle is flexed at 30 degrees, and the foot is placed on the fluoroscopic table. The foot should be flat without inversion or eversion, and the X-ray source is positioned 30 degrees anterior to the foot tip in a direction oblique to the foot. For lateral views of the foot, the patient stands with the medial edge of the foot against the erect fluoroscopic table in a neutral ankle position, and the X-ray source is projected vertically from the lateral side of the foot. (Figure 1, cited from Reference 1)

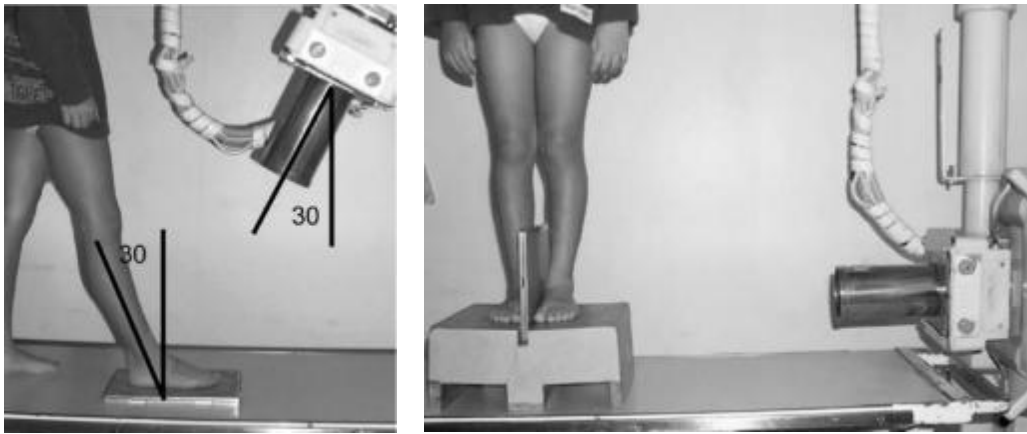


Figure 1 Anteroposterior (anteroposterior) projection and lateral projection
Fig. 1 AP projection and Lateral projection

2.3.2 Imaging evaluation measurement indicators

The normal values of foot imaging in children vary greatly and are closely related to age. This study mainly measured the ankle X-ray of children aged 5-6 years, including a small number of children aged 4 and 7 years. All the ankle X-ray measurements were based on standard standing anteroposterior foot X-rays.

The measurements of various indicators in this study were first conducted by two professional pediatric orthopedic physicians who had received pre-study imaging measurement training (one senior attending physician and one attending physician). The consistency of results within and between groups was then statistically evaluated using the Spearman correlation coefficient. The Spearman coefficients for intra-group and inter-group comparisons were 0.92 and 0.88, respectively, indicating that the imaging measurement results of this study have good consistency.

(1) Radius of curvature of the talar dome, opening Angle of the talar dome and longest diameter of the longitudinal axis of the talus

According to the literature report [2], on the lateral view of the foot in standing position, the radius of the circle coinciding with the talar fornix is the talar fornix

The radius of curvature radius of curvature of the talar dome (R), the angle between the line from the front edge of the slip to the center and the line from the back edge to the center is the talus fossa opening angle opening angle of the talus dome (α -angle), and the longest diameter from the head of the talus to the distal end of the talus is the talus length the length of the talus (L). This primarily assesses the development of the talus and is believed to be closely related to the flexion and extension function of the ankle joint. The measurement method is shown in Figure 2.





Figure 2 Radius of curvature of the talar dome, longest diameter of the longitudinal axis of the talus, and opening Angle of the talar dome

(2) The maximum length, width and height of the ossification nucleus of the talus bone

According to the measurement method of the third cuneiform bone reported by Dr Lang et al. [3], the ossification nucleus of the navicular bone was measured in this study.

On anteroposterior foot films, the length of the line connecting the two ends of the long axis of the navicular bone is the maximum diameter (Max. Length of navicular OC) of the navicular bone ossification nucleus; the length of the line connecting the two ends of the short axis of the navicular bone is the maximum diameter (Max. width of navicular OC) of the navicular bone ossification nucleus. On lateral foot films, the length of the line connecting the anterior and posterior edges of the navicular bone is the maximum diameter (Max. width of navicular OC) of the navicular bone ossification nucleus; the length of the line connecting the upper and lower edges of the navicular bone is the maximum diameter (Max. height of navicular OC) of the navicular bone ossification nucleus. The measurement methods are shown in Figure 3. The product of the maximum diameters of the length, width, and height of the navicular bone ossification nucleus represents, to some extent, the size (dimensions of navicular OC) of the navicular bone ossification nucleus.



Fig.3 Max. Length,width,height of navicular OC

(3) Long feet, wide forefeet and wide hindfeet

The foot development of children with clubfoot is slower than that of normal feet. Literature has studied the length and width of the affected foot. Referring to the report by Dr Wallace et al. [4], this study defines the length between the anterior and posterior tangential lines of the foot as the foot length (foot length) on an anteroposterior view of the foot in standing position; the length between the medial and lateral tangential lines of the forefoot as the forefoot width (forefoot widths); and the length between the medial and lateral tangential lines of the hindfoot as the hindfoot width (heel widths).



Figure 4. Long feet, wide forefeet and wide hindfeet

(4) Lateral tibial angle and lateral tibial heel Angle

According to Dr Kang et al. [5], the lateral tibiofibular angle has become a decisive factor in whether children with idiopathic equinovarus should undergo percutaneous Achilles tendon release surgery. On lateral foot radiographs, the angle between the tibial axis and the talus axis is measured as the lateral tibiofibular angle (lateral tibio-talar angle, LTTA), and the angle between the tibial axis and the fibular axis is measured as the lateral tibiofibular angle (lateral tibiocalcaneal angle, LTiCA). The measurements are shown in Figure 5.

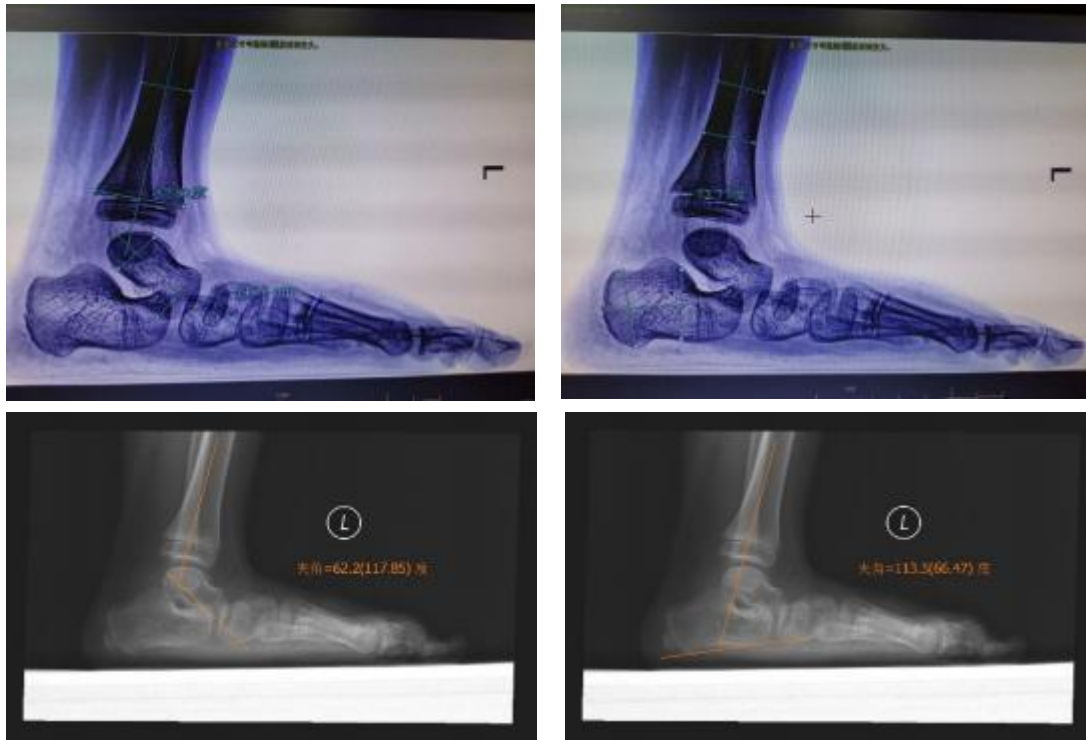


Figure 5 Lateral tibial Angle, lateral tibiofibular Angle

2.4 Statistical analysis

The statistical analysis was performed using STATA 15.1 (Copyright 1985-2017 StataCorp LLC). In the study comparing the foot development of children with clubfoot treated by Ponseti at different ages, the differences in the curvature radius of the talus trochlea, the opening angle of the talus trochlea, the longest diameter of the longitudinal axis of the talus, the maximum diameters of the calcaneal ossification nucleus, foot length, forefoot width, hindfoot width, lateral tibiofibular angle, and lateral tibiofibular heel angle were analyzed using independent samples t-tests (Student's t test). The impact of the Ponseti treatment process on the curvature radius of the talus trochlea, the opening angle of the talus trochlea, the longest diameter of the longitudinal axis of the talus, the maximum diameters of the calcaneal ossification nucleus, foot length, forefoot width, and hindfoot width, as well as their risk factors, were analyzed using multivariate logistic regression. A $p < 0.05$ was considered statistically significant.

3 Results

3.1 Basic information of the included children

From October 2007 to December 2013, a total of 328 children with clubfoot underwent consecutive visits, and 317 cases completed plaster correction treatment. Among these, 35 cases had postural, neuromuscular, multi-joint contracture, syndrome, or combined limb dysplasia. Twenty cases had undergone surgery or non-surgical treatments before the visit. One hundred and ten cases were lost to follow-up or followed for less than 5 years, and 73 cases had incomplete data, non-standard imaging data, initial treatment age over 2 years, or wore braces for less than 1 year after recurrence treatment. A total of 79 cases met the criteria and were finally included in the study. Specific clinical indicators are detailed in the first part of this paper.

3.2 Analysis of the effect and prognosis of Ponseti method on foot development in talipes valgus

3.2.1 Study on the comparison of foot development of children with clubfoot treated by Ponseti method at different ages

According to the initial treatment age in January and March, 79 children with clubfoot treated by Ponseti method were divided into three groups:

Group I <1 month, Group II $\geq$ 1 month, <3 months, Group III $\geq$ 3 months. From the results in Table 1, it can be seen that Group III has a larger tibiofibular angle and a larger calcaneal angle, with the former showing statistically significant differences from Group II and the latter from Group I ($p < 0.05$). However, among different age groups, no significant differences were observed in other foot development indicators ($p > 0.05$). Therefore, the study results suggest that delayed treatment did not significantly affect foot development compared to early treatment.

Table 1 Comparison of foot development of children with clubfoot treated by Ponseti method at different ages

TABLE 1. A comparative study of foot development with respect to presentation age on the Ponseti management for clubfoot										
	Mean $\pm$ SD or N			P value						
	Group I	Group II	Group III	Group I Vs. II	Group I Vs. III	Group II Vs. III				
Radius of curvature of the talar dome	13.85 $\pm$ 2.60	13.40 $\pm$ 2.78	13.21 $\pm$ 2.55	0.728	0.645	0.967				
Length of the talus	33.65 $\pm$ 4.90	33.07 $\pm$ 4.58	32.81 $\pm$ 0.86	0.862	0.805	0.981				
R/L	0.41 $\pm$ 0.07	0.40 $\pm$ 0.06	0.40 $\pm$ 0.06	0.786	0.842	1.000				
Open angle of the talar dome	87.32 $\pm$ 28.75	84.31 $\pm$ 32.18	94.40 $\pm$ 28.21	0.891	0.647	0.466				
Max. length of navicular OC	10.39 $\pm$ 7.94	9.28 $\pm$ 7.36	10.20 $\pm$ 6.61	0.782	0.995	0.906				
Max. width of navicular OC	5.24 $\pm$ 4.04	4.14 $\pm$ 3.52	5.31 $\pm$ 3.50	0.386	0.998	0.531				

Max. height of navicular OC	8.78±6.63	7.94±6.20	8.77±5.93	0.824	1.000	0.894
Tibio-talar angle	86.64±30.77	79.75±24.70	99.70±28.95	0.520	0.205	0.043
Tibiocalcaneal angle	81.97±9.37	85.90±10.81	89.4±14.08	0.225	0.028	0.496
Foot length	173.86±17.25	174.53±16.62	171.09±17.08	0.983	0.815	0.761
Forefoot widths	71.01±7.12	70.81±5.88	71.21±7.15	0.990	0.994	0.977
Heel widths	58.86±6.46	58.71±5.42	59.70±5.85	0.993	0.861	0.836

3.2.2 Study on the effect of Ponseti method on talus development in equinus varum

(1) R/L ratio

The statistical results indicate that during the treatment of Ponseti, risk factors such as the initial degree of deformity in children with clubfoot, the number of casts used for initial correction, whether PAT was performed, the initial correction rate, compliance with orthotic devices, and recurrence rate did not significantly affect the change in R/L values. Multivariate analysis showed no significant differences (Table 2, $p>0.05$). The gender of the child, age at initial treatment, age at R/L measurement, and side of the foot also did not significantly impact the change in R/L values; multivariate analysis revealed no significant differences (Table 3, $p>0.05$). However, the greater the dorsiflexion angle of the ankle joint during bilateral and initial correction of the deformity, the smaller the R/L value, which is more favorable for the development of the subtalar fossa. Multivariate analysis showed a significant difference (Table 3, $p<0.05$).

Table 2. The effect of Ponseti, method and treatment process on R/L

Table 2. The impact on R/L in the procedure of Ponseti method				
Influence Factors	Coef.	t	P	(95% CI*)
Dimeglio score	-0.003	-1.07	0.286	(-0.0097-0.0029)
Pirani score	0.019	1.95	0.053	(-0.0003-0.0383)
Number of casts	0.005	1.12	0.265	(-0.0037-0.0134)
PAT	0.023	1.10	0.273	(-0.0182-0.0639)
Correction rates	0.039	1.76	0.082	(-0.0051-0.0835)
Compliance rate	0.013	0.60	0.548	(-0.0303-0.0568)
Relapse	0.006	0.36	0.723	(-0.0288-0.0413)

Table 3. Risk factors of R/L study

Table 3. The study of the risk factors of R/L				
Risk Factors	Coef.	t	P	(95% CI*)
Gender	0.006	0.46	0.646	(-0.0186-0.0299)
Age	-0.0027	-1.70	0.091	(-0.0578-0.0004)
Age of examination	0.0051	-0.97	0.332	(-0.0153-0.0052)
Unilateral/bilateral	0.0211	2.06	0.041	(0.0009-0.0412)
Side	0.0098	1.04	0.298	(-0.0088-0.0284)
AT dorsiflexion	-0.0017	-2.90	0.004	(-0.0029--0.0005)

(2) Angle α

The statistical results indicate that during the treatment of Ponseti, risk factors such as the initial degree of deformity in children with clubfoot, the number of casts used for initial correction, the initial correction rate, and recurrence rate did not significantly affect changes in α values. Multivariate analysis showed no significant differences ($p>0.05$). However, performing PAT surgery ($p=0.05$) and good compliance with orthotic devices ($p<0.05$) reduced α values (as shown in Table 4). Additionally, the child's gender, age at initial treatment, age at α measurement, unilateral or bilateral, left or right side, and ankle dorsiflexion angle at initial correction did not significantly impact changes in α values. Multivariate analysis also showed no significant differences (Table 5, $p>0.05$).

Table 4. Effects of Ponseti, method and treatment process on α Angle

Table 4. The impact on α angle in the procedure of Ponseti method				
Influence Factors	Coef.	t	P	(95% CI*)
Dimeglio score	2.043	1.46	0.147	(-0.7326-4.8182)
Pirani score	-6.075	-1.41	0.160	(-14.5860-2.4366)
Number of casts	-1.305	-0.69	0.495	(-5.0768-2.4678)
PAT	-18.096	-1.98	0.050	(-36.2122-0.0201)
Correction rates	-14.219	-1.44	0.153	(-33.7818-5.3428)
Compliance rate	-24.072	-2.48	0.015	(-43.3084--4.8352)
Relapse	4.390	0.56	0.575	(-11.0924-19.8719)

Table 5. Risk factors for α Angle

Table 5. The study of the risk factors of α angle				
Risk Factors	Coef.	t	P	(95% CI*)
Gender	1.157	0.18	0.858	(-11.6174-13.9308)
Age	0.8666	1.05	0.296	(-0.7657-2.4988)
Age of examination	0.2764	0.10	0.920	(-5.1295-5.6823)
Unilateral/bilateral	-4.5431	-0.85	0.398	(-15.1389-6.0527)
Side	-2.3962	-0.48	0.629	(-12. 1733-7.3809)
AT dorsiflexion	-.08920	-0.29	0.773	(-0.7003-0.5219)

3.2.3 Study on the effect of Ponseti method on the development of navicular bone in talipes valgus

The statistical results indicate that during the treatment of Ponseti, risk factors such as the initial degree of deformity in children with clubfoot, the number of casts used for initial correction, whether PAT was performed, the initial correction rate, compliance with orthotic devices, and recurrence rate did not significantly affect changes in the size of the calcaneal ossification nucleus.

Multivariate analysis showed no significant differences (Table 6, $p>0.05$). Additionally, the child's gender, age at initial treatment, unilateral or bilateral involvement, left or right side, and the dorsiflexion angle of the ankle joint at the time of initial correction did not significantly impact changes in the size of the calcaneal ossification nucleus. Multivariate analysis also showed no significant differences (Table 7, $p>0.05$). However, the older the child measured, the larger the calcaneal ossification nucleus, and multivariate analysis revealed significant differences (Table 7, $p<0.05$).

Table 6. Effects of Ponseti method on the size of ossification nucleus of navicular bone

Table 6. The impact on dimensions of navicular OC in the procedure of Ponseti method

Influence Factors	Coef.	t	P	(95% CI*)
Dimeglio score	32.14	0.54	0.588	(-85.25-149.52)
Pirani score	-227.50	-1.25	0.213	(-587.49-132.49)
Number of casts	155.21	1.93	0.056	(-4.34-314.76)
PAT	-416.68	-1.08	0.283	(-1182.90-349.54)
Correction rates	-670.43	-1.61	0.111	(-1497.82-156.95)
Compliance rate	151.49	0.37	0.713	(-662.12-965.10)
Relapse	1738.48	1.78	0.078	(-198.33-3675.29)

Table 7. Risk factors for the size of ossification nucleus of talus**Table 7. The study of the risk factors of dimensions of navicular OC**

Risk Factors	Coef.	t	P	(95% CI*)
Gender	394.51	1.46	0.146	(-138.48-927.50)
Age	-20.80	-0.60	0.547	(-88.91-47.30)
Age of examination	867.10	7.60	0.000	(641.54-1092.66)
Unilateral/bilateral	-406.28	-1.82	0.071	(-848.38-35.83)
Side	-242.46	-1.17	0.242	(-650.40-165.49)
AT dorsiflexion	19.69	1.53	0.129	(-5.80-45.19)

3.2.4 Study on the effect of Ponseti method on the development and size of foot appearance in talipes valgus

As we all know, the foot development size of children with talipes equinovarus is smaller than that of normal feet, and almost half of the children are unilateral. The asymmetrical development of both feet makes it difficult for children to find suitable shoes in life. Therefore, studying the significance of foot appearance development size for the treatment and follow-up of children with talipes equinovarus is very important.

(1) Foot length

The statistical results indicate that during the treatment of Ponseti, risk factors such as the initial degree of deformity in children with clubfoot, the number of casts used for initial correction, whether PAT was performed, the initial correction rate, compliance with orthotic devices, and recurrence rate did not significantly affect the length of the child's foot. Multivariate analysis showed no significant differences (Table 8, $p>0.05$). The younger the child and the earlier the age at initial treatment, the shorter the foot length; conversely, the older the child and the later the age at measurement, the longer the foot length. Multivariate analysis revealed significant differences (Table 9, $p<0.05$). Additionally, whether the child had unilateral or bilateral deformities, and the ankle dorsiflexion angle at the time of initial correction did not significantly affect the length of the foot. Multivariate analysis showed no significant differences (Table 9, $p>0.05$).

Table 8. The impact on foot length in the procedure of Ponseti method

Influence Factors	Coef.	t	P	(95% CI*)
Dimeglio score	0.1047	0.12	0.902	(-1.5836-1.7930)
Pirani score	-1.5623	-0.60	0.551	(-6.7397-3.6152)
Number of casts	0.4382	0.38	0.706	(-1.8565 -2.7329)
PAT	-5.9109	-1.06	0.290	(-16.9309-5.1091)
Correction rates	-5.8848	-0.98	0.329	(-17.7845-6.0149)
Compliance rate	-2.6815	-0.45	0.651	(-14.3831-9.0201)
Relapse	-0.6000	-0.13	0.900	(-10.0177-8.8178)

Table 9. The study of the risk factors of foot length

Risk Factors	Coef.	t	P	(95% CI*)
Gender	-12.2148	-4.00	0.000	(-18.2477--6.1819)
Age	-0.7842	-2.01	0.046	(-1.5551--0.0133)
Age of examination	9.3641	7.25	0.000	(6.8110-11.9172)
Unilateral/bilateral	-3.5453	-1.40	0.164	(-8.5494-1.4589)
Side	0.6771	0.29	0.772	(-3.9403-5.2946)
AT dorsiflexion	0.2647	1.81	0.072	(-0.0239-0.5532)

(2) Wide forefoot

The statistical results indicate that during the treatment with Ponseti, risk factors such as the initial degree of deformity in children with clubfoot, the number of casts used for initial correction, whether PAT was performed, the initial correction rate, compliance with orthotic devices, and recurrence rate did not significantly affect the width of the forefoot in children. Multivariate analysis showed no significant differences (Table 10, $p>0.05$). Male patients had a smaller forefoot compared to females, and the older the child at measurement, the larger the forefoot. Multivariate analysis revealed significant differences (Table 11, $p<0.05$). The initial age of treatment, unilateral or bilateral, left or right side, and the dorsiflexion angle of the ankle joint at the time of initial correction did not significantly affect the width of the forefoot. Multivariate analysis showed no significant differences (Table 11, $p>0.05$).

Table 10. The impact on forefoot width in the procedure of Ponseti method

Influence Factors	Coef.	t	P	(95% CI*)
Dimeglio score	-0.5271	-1.58	0.117	(-1.1875-0.1333)
Pirani score	1.3242	1.30	0.198	(-0.7011-3.3495)
Number of casts	0.4478	0.99	0.325	(-0.4498-1.3454)
PAT	0.0042	0.00	0.998	(-4.3066- 4.3150)
Correction rates	- 3.2065	-1.37	0.175	(-7.8614-1.4484)
Compliance rate	0.2029	0.09	0.930	(-4.3745-4.7803)
Relapse	0.2869	0.15	0.878	(-3.3972-3.9709)

Table 11. Risk factors for forefoot width

Table 11. The study of the risk factors of forefoot width				
Risk Factors	Coef.	t	P	(95% CI*)
Gender	-5.0646	-4.17	0.000	(-7.4636--2.6656)
Age	-0.2864	-1.85	0.067	(-0.5929--0.0201)
Age of examination	2.5026	4.87	0.000	(1.4874-3.5178)
Unilateral/bilateral	0.0806	0.08	0.936	(-1.9093-2.0705)
Side	-0.7476	-0.80	0.422	(-2.5837-1.0886)
AT dorsiflexion	-0.0586	-1.01	0.315	(-0.1733-0.0562)

(3) Wide hind feet

The statistical results indicate that during the treatment with Ponseti, the higher the Dimeglio score for children with clubfoot deformity, the smaller the width of the hindfoot, with a statistically significant difference (Table 12, $p < 0.05$). However, Pirani scores, the number of casts used for initial correction, whether PAT was performed, the initial correction rate of deformity, patient compliance with orthoses, and recurrence rates did not significantly affect changes in the width of the hindfoot. Multivariate analysis showed no significant differences (Table 12, $p > 0.05$). Male patients had a smaller hindfoot width compared to females, and the older the age at measurement, the larger the hindfoot width, with significant differences found in multivariate analysis (Table 13, $p < 0.05$). The initial treatment age, unilateral or bilateral, left or right side, and the dorsiflexion angle of the ankle joint at the time of initial correction did not significantly affect the size of the hindfoot width, with no significant differences found in multivariate analysis (Table 9, $p > 0.05$).

Table 12. Effects of Ponseti method on the width of the hind foot

Table 12. The impact on heel width in the procedure of Ponseti method				
Influence Factors	Coef.	t	P	(95% CI*)
Dimeglio score	-0.6549	-2.22	0.028	(-1.2395--0.0702)
Pirani score	1.6856	1.86	0.065	(-0. 1073-3.4785)
Number of casts	-0.2330	-0.58	0.562	(-1.0276-0.5617)
PAT	-0.4225	-0.22	0.827	(-4.2387-3.3937)
Correction rates	-3.5562	-1.71	0.090	(-7.6770-0.5646)
Compliance rate	-0.2156	-0.11	0.916	(-4.2678-3.8366)
Relapse	-0.2495	-0.15	0.880	(-3.5109- 3.0118)

Table 13. Risk factors for wide heels

Table 13. The study of the risk factors of heel width				
Risk Factors	Coef.	t	P	(95% CI*)
Gender	-4.6381	-3.88	0.000	(-6.9982--2.2780)

Age	-0.2243	-1.47	0.144	(-0.5259-0.0773)
Age of examination	1.4079	2.79	0.006	(0.4091-2.4066)
Unilateral/bilateral	0.3163	0.32	0.750	(-1.6414-2.2739)
Side	-0.9056	-0.99	0.324	(-2.7119-0.9008)
AT dorsiflexion	0.0253	0.44	0.659	(-0.0876-0. 1382)

3.3 The effect of foot measurement on the development after Ponseti treatment on the final evaluation results of follow-up

3.3.1 The effect of foot measurement on the development of ankle dorsiflexion function at the end of follow-up

The statistical results indicate that at the end of the follow-up for Ponseti treatment, the larger the R/L, the smaller the final ankle dorsiflexion angle in children with clubfoot, with a statistically significant difference (Table 15, $p < 0.05$). The larger the α angle, the smaller the final ankle dorsiflexion angle, but this difference is not statistically significant (Table 15, $p = 0.057$). However, lateral tibiofibular angle and tibiofibular angle measurements did not significantly affect the final ankle dorsiflexion angle in children, and no significant differences were observed in multivariate analysis (Table 14, $p > 0.05$).

Table 14. Effects of foot measurement on the development of ankle dorsiflexion function at the end of follow-up

Table 14. The impact of foot development on final dorsiflexion				
Influence Factors	Coef.	t	P	(95% CI*)
R/L	-40.7067	-2.98	0.003	(-67.7113--13.7021)
A angle	-0.0712	-1.92	0.057	(-0.1446-0.0021)
Tibiotalar angle	-0.0096	-0.29	0.769	(-0.0743-0.0550)
Tibiocalcaneal angle	-0.0253	-0.39	0.696	(-0.1529-0. 1024)

3.3.2 Risk factors for the study of foot development on the International Study Group of Horseshoe Inversion

The statistical results indicate that at the end of Ponseti treatment follow-up, the wider the posterior foot width in children with clubfoot, the higher the final ICFSG score of the deformed foot, with statistically significant differences (Table 15, $p < 0.05$). However, R/L, α angle, calcaneal ossification, foot length, and forefoot width did not significantly affect the change in the final ICFSG score of the deformed foot, and no significant differences were observed in multivariate analysis (Table 15, $p > 0.05$).

Table 15. Risk factors for foot development assessed by the International Study Group on Horseshoe Equestrianism

Risk Factors	Coef.	t	P	(95% CI*)
R/L	-0.5785	-0.18	0.857	(-6.9478-5.7909)
A angle	0.0095	1.35	0.180	(-0.0044-0.0233)
navicular OC	0.0001	0.86	0.394	(-0.0002-0.0005)
Foot length	-0.0020	-0.12	0.903	(-0.0340-0.0301)
Forefoot width	-0.0518	-1.16	0.249	(-0.1405-0.0369)
Heel width	0.0973	2.28	0.025	(0.0127-0. 1818)

4 Discussion

During infancy, the ossification center (OC) of the talus is relatively small within a large cartilaginous mass. During growth and development, the ossification core extends from the center of the bone outward, forming the shape of the cartilaginous base through continuous manual manipulation and plaster molding according to the Ponseti method. The treatment plan is based on a good understanding of the functional anatomy and biological response of all foot structures, gradually achieving the correct positional changes. It is possible to predict the shape of the talus based on the shape of the ossification core. Pirani et al. [6] used MRI follow-up to re-examine children with clubfoot treated with the Ponseti method. In their study, they were able to demonstrate what happened between each plaster correction: the correction of the wedge-shaped calcaneal bone, medial tilt of the talus, and medial displacement of the navicular bone; the correction of the wedge-shaped distal calcaneal joint surface and medial displacement of the cuboid bone; and the correction of the inverted calcaneus back to its normal position. Once the talus maintains a normal three-dimensional relationship with the corresponding shaped cartilage and sufficient ossification volume, the foot can better resist the tendency for recurrent clubfoot. The recommended time for Ponseti treatment of congenital clubfoot is from birth to 6 months. As more cases of recurrence and neglected patients emerge, some surgeons have attempted to treat older children with the Ponseti method without age restrictions, ultimately achieving satisfactory clinical outcomes and reducing the risk of over-surgery [7-13]. Walking equine foal clubfoot presents significant challenges for deformity correction, primarily due to the high degree of ossification and maturation of the bone-joint system and the increasing stiffness of soft tissues. This study divided 79 children with clubfoot treated using the Ponseti method into three groups based on initial treatment age at 1 month and 3 months. Children treated after 3 months had larger tibiofibular angles and tibiofibular angles, while no significant differences were observed in other foot development indicators across the age groups. This suggests that delayed treatment did not significantly alter foot development compared to early treatment.

In successful talus varus foot treatment, the development and ultimate shape of the talus not only determine the range of motion of the ankle joint but are also major predictors of both short-term and long-term osteoarthritis of the ankle joint[14]. Therefore, in the treatment and follow-up

studies of talus varus foot, analyzing the formation of osteoarthritis of the ankle joint due to various types of talus deformities is crucial. Currently, there are few studies on the types of talus deformities associated with idiopathic talus varus foot and their clinical symptoms. Kolb et al. divided the talus into two groups based on the size of the radius-to-length ratio (R/L) after treatment: the talus with a smaller R/L ratio was classified as small dome deformity (SD), and the talus with an increased R/L ratio was classified as flat dome deformity (FT). The results showed that in the small dome deformity (SD) group, the open angle of the talus increased, which was associated with an increase in ankle joint range of motion ($p = 0.033$), but the impact on the onset of arthritis was not significant ($p = 0.056$). In the flat dome deformity group, the open angle of the talus decreased, and the range of motion reduced ($p = 0.019$), with a significant difference in the impact on the onset of arthritis ($p = 0.010$)[2]. Therefore, this R/L ratio and talus open angle were used to evaluate the development of the talar fossa, while first studying the risk factors affecting its size. The results suggest that during Ponseti treatment, the greater the initial ankle dorsiflexion angle and the smaller the R/L value at the onset of bilateral involvement and deformity, the more favorable it is for the development of the talar fossa. Multivariate statistics show significant differences, and PAT surgery ($p=0.05$) and better brace compliance ($p<0.05$) reduce α values, indicating that after PAT surgery, the development of the talar trochlea in children with extreme ankle dorsiflexion and longer effective brace wearing time is somewhat affected.

Studies such as those by Miyagi et al. indicate that the ossification of the talus in children with unilateral congenital clubfoot occurs later than on the contralateral side, with an average age of 5 years and 2 months for the navicular bone and 3 years and 10 months for the medial cuneiform. In contrast, the normal side has an average age of 3 years and 10 months for the navicular bone, which is the last to ossify, and 3 years and 1 month for the medial cuneiform. The differences are statistically significant, but further research is needed on the impact of imaging measurements of the size of the ossification center of the affected talus on the treatment process and prognosis. In anatomical studies of clubfoot, the navicular bone is small in volume and has a normal shape, which correlates positively with the severity of talus deformity [16]. Pirani et al. described a long wedge-shaped navicular bone, which is flatter on the lateral and dorsal surfaces compared to the base [6]. These findings were supported by studies by Napiontek et al., who described a reduction, flattening, fragmentation, cystic changes, and wedge-shaped [17] in the ossification center of the navicular bone. The results of this study suggest that during Ponseti treatment, risk factors such as the initial degree of deformity, the number of casts used for initial correction, whether a PAT was performed, the initial correction rate of deformity, patient compliance with braces, and recurrence rate do not significantly affect the size of the ossification center of the navicular bone. Additionally, the sex of the child, the age at initial treatment, whether it is unilateral or bilateral, left or right side, and the ankle dorsiflexion angle at the time of initial correction do not significantly influence the

size of the ossification center of the navicular bone. However, the older the child was at measurement, the larger the ossification nucleus of the calcaneus, and there were significant differences in multivariate statistics.

The [18] measurements and statistical analyses by Kesemenli et al. found that the affected foot of patients with unilateral talipes equinovarus was shorter than the contralateral normal foot, and this difference was more pronounced in surgical patients. The older the patient, the more significant this difference became. Both groups had smaller affected feet compared to their contralateral normal feet, but this difference was not statistically significant. However, Hutchins et al. reported that [19] showed that the affected foot was shorter and wider after surgery compared to the contralateral normal foot. In our center's treatment using the Ponseti method, male patients with initial treatment age younger had shorter feet, which showed a significant difference in multivariate analysis. Additionally, male patients had narrower forefeet compared to females, showing a significant difference in multivariate analysis. The severity of the initial deformity in the affected foot, as measured by the Dimeglio score, was greater, and the width of the hindfoot was smaller, with statistically significant differences. Male patients had narrower hindfeet compared to females, showing a significant difference in multivariate analysis. Moreover, the greater the width of the hindfoot in patients with talipes equinovarus, the higher the ICFSG score indicating the severity of the deformity, and the poorer the treatment outcome, with significant statistical differences.

Kelly A et al. [20] found in a 10-year follow-up study that foot deformities treated with non-surgical methods showed better ankle strength and movement intensity compared to those treated with intra-articular surgery. Both non-surgical and surgical treatments had significant effects on the dorsiflexion of the ankle in congenital clubfoot and equine navicular insufficiency. This was also evident in our clinical follow-up measurements, where the dorsiflexion of the ankle is closely related to the development of the talus dome. The larger the R/L ratio, the smaller the final follow-up dorsiflexion angle of the ankle in patients, the differences were statistically significant, but the measurements of α angle, lateral tibiofibular angle, and tibiofibular angle did not significantly affect the final ankle dorsiflexion angle in children. Multivariate statistics showed no significant differences. Perveen et al. [8] believed that the squatting posture plays a crucial role in evaluating the clinical outcomes of older patients, as the ability to squat is associated with non-everted heel posture, good ankle mobility, higher total functional outcome scores, and walking ability.

5 Summary

- 1) There was no significant difference in foot development between the delayed treatment group and the early treatment group.

- 2) The greater the dorsiflexion angle of the ankle joint at the initial correction of bilateral and malformation in patients, the smaller the R/L value, which is more conducive to the development of the talus fossa. Performing PAT surgery ($p < 0.05$) and better compliance with braces ($p < 0.05$) reduce

the α value; the larger the R/L value, the smaller the final dorsiflexion angle of the ankle joint in patients with equinus, and the measurements of the α angle, lateral tibiofibular angle, and tibiofibular angle do not significantly affect the final change in the dorsiflexion angle of the ankle joint in patients.

3) During the Ponseti treatment process, initial deformity severity, the number of splints used for initial correction, whether PAT was performed, initial correction success rate, patient compliance with orthoses, and recurrence rate did not significantly affect the size of the navicular bone ossification center. The patient's gender, age at initial treatment, unilateral or bilateral, left or right side, and the ankle dorsiflexion angle at the time of initial correction also did not significantly impact the size of the navicular bone ossification center. However, the older the patient measured to be, the larger the navicular bone ossification center.

4) At the time of measurement around age 5, male patients had shorter feet with younger initial treatment age; male patients had narrower forefeet and hindfeet; the higher the Dimeglio score for the initial degree of deformity in clubfoot patients, the smaller the hindfoot width; the larger the hindfoot width, the higher the final ICFSG score for the deformed foot.

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