








Using the modified Ponseti method to treat complex clubfoot: Early results

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Congenital talipes equinovarus (clubfoot) has an incidence of one to two per 1,000 live births and is among the most frequently treated orthopedic diseases.^[1] The Ponseti method became the gold standard treatment for clubfoot worldwide after the 1990s.^[2-7] However, the widespread use of the Ponseti method has made it clear that treatment results can vary. Some babies have atypically shaped feet that do not respond well to the treatment.^[8]

In these cases, the Achilles tendon is long and wide, the calf muscles are short, and the plantar muscles and ligaments are tight. These characteristics increase the level of deformity observed in the heel and forefoot. Equinus and varus deformities of the heel are more severe, and there is a deep crease above the heel. Forefoot adduction and supination are also more severe. There is severe flexion of all metatarsals, causing

ABSTRACT

Objectives: This study aims to present the results of complex clubfoot patients treated with modified Ponseti method and put forth the warning clinical signs of complex deformities.

Patients and methods: A total of 11 patients (10 males, 1 female; mean age 60.1±49.7; range, 2 to 180 days) with 16 complex clubfeet treated with modified Ponseti method were included in this study conducted between January 2016 and June 2019. All the data of the patients were collected prospectively and reviewed retrospectively. Demographic features, clubfoot severity, number of casts, position of each foot before cast removal, ankle dorsiflexion (DF), complications, and additional procedures were noted at all clinical visits.

Results: Eleven (11.2%) of 98 patients had complex clubfoot deformity. Six (7.7%) of 78 newly diagnosed patients and five (25%) of 20 referred patients had complex clubfeet. We treated 16 complex clubfeet of 11 patients. The mean follow-up period was 13.3 (range, 10 to 16) months. All deformities were initially corrected using a mean of seven (range, 5 to 8) casts and Achilles tenotomy. Relapses occurred in three (18.75%) patients, but all recovered after recasting. The creases above the heels disappeared in all of the patients, whereas plantar creases persisted on two (12.5%) feet. Pirani scores and DF improved statistically significantly after treatment, and DF improved significantly between tenotomy and the final visit.

Conclusion: The modified Ponseti method is an effective treatment for complex clubfoot. Classical clinical appearance, treatment-resistant deformities and referred patients should be warning signs for complex clubfoot.

Keywords: Clubfoot, complex clubfoot, modified Ponseti method, Ponseti method.

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severe cavus. The first toe is hyperextended, and there is a deep crease on the plantar surface of the foot (Figure 1).^[5,9-11] As a result, the foot is very short and stubby. This subgroup of patients have complex clubfoot, and the Ponseti method is insufficient to resolve the condition.^[5,9] Ponseti et al.^[5] described this subgroup of patients, together with the modified Ponseti method.

The complex clubfoot deformity is seen rarely and few publications have been presented about complex clubfoot.^[5,9-11] Sometimes, it may be difficult to diagnose the condition, and many orthopedic clinicians do not know how to implement the modified treatment. In this study, we aimed to present the results of complex clubfoot patients treated with modified Ponseti method and put forth the warning clinical signs of complex deformities.

PATIENTS AND METHODS

This study was conducted at Harran University Faculty of Medicine, Department of Orthopedics and Traumatology, between January 2016 and June 2019. All the data of the patients were collected prospectively and reviewed retrospectively. We began to treat 78 patients with idiopathic clubfeet. Six of these patients had complex deformities (7.7%). During this period, 20 patients were referred from other institutions after unsuccessful initial treatments and five of them were diagnosed as having complex clubfeet. In total, 11 (11.2%) (10 males, 1 female; mean age: 60.1 ± 49.7 ; range, 2 to 180 days) of the 98 patients had complex deformity and formed the study group. Patients with myelomeningocele, arthrogryposis, neuromuscular disease, or any other clubfoot-related syndrome were excluded. The study protocol was approved by the Harran University Faculty of Medicine Ethics Committee (12/07/2019-E.29941). A written informed consent was obtained from the legal guardians of each patient. The study was conducted in accordance with the principles of the Declaration of Helsinki.

An experienced clubfoot specialist maintains the records for all patients at our clinic. During a patient's first visit, demographic characteristics are recorded and the Pirani score is calculated. Generally, patients with complex clubfeet are recognized at this point and followed-up more carefully. In patients referred from other institutions, we often observe signs of compression on the feet, such as erythema and edema. We allow these problems to subside before commencing treatment (Figure 1).

All casts were applied by the same orthopedic surgeon. For complex clubfoot deformities, we started the treatment according to modified Ponseti method and followed all the steps of modified Ponseti method strictly. After the last cast, we evaluated the ankle dorsiflexion (DF) and calculated Pirani scores after five to eight casts. If ankle DF was less than 10° , we performed a mini open Achilles tenotomy in the operating room and applied a cast for three weeks. After removing the cast, we evaluated the ankle DF

and calculated the Pirani scores again. If the foot was sufficiently corrected, a foot abduction brace (FAB) was worn for at least 23 h per day. The feet were held within the FAB at 40° abduction, as in the cast. After the patient had worn the FAB for 15 days, we invited the parents to a clinical visit to determine whether they could fit the FAB correctly. If the parents could fit the FAB without difficulty, monthly follow-up visits were scheduled. At all clinical visits, we recorded ankle DF measurements and calculated Pirani scores. We examined the patients for signs of relapse (e.g., equinus of the foot, forefoot adduction or heel varus) and ensured the FAB was being fitted correctly. After 3.5 months, the FAB was to be worn during night sleep and naps. We continued



FIGURE 1. A 2.5-month-old patient with bilateral complex clubfoot following an unsuccessful treatment involving seven casts. (a, b) Feet are edematous and erythematous. First toes are short and hyperextended. Feet are short and stubby, with creases on the plantar surfaces. (c, d) 16-month visit: feet are no longer short, stubby and puffy, and posterior creases have disappeared. Dorsiflexion measurements were satisfactory. (e) Plantar creases disappeared and bilateral heel varus was corrected.

to follow-up patients on a monthly basis until they were 12 months of age. Thereafter, if there was no relapse, we scheduled visits for every three months and suggested the patients to wear the FAB until they were five years old.

At the beginning of treatment, we follow the same steps in both modified and standard Ponseti methods. In the first step, we correct the cavus deformity and then start to correct the adductus deformity. If the patient was referred from another institution and we diagnosed the complex clubfoot, we applied the modified method. In our clinic, if we diagnose a complex clubfoot at the patient's first application, we apply the modified method again. The risky patients are followed-up carefully and as the clinical characteristics of complex clubfoot become more evident, we proceed with modified Ponseti method. There was no difference in treatment steps if the patients' treatment had begun in our institution or he or she was referred from another institution. To correct the complex clubfoot, it is necessary to locate the talar head and subtalar joint precisely. The most prominent points to identify are the lateral malleolus and the anterior tuberosity of the calcaneus. We locate the talar head using these anatomical guides and try to move the subtalar joint. During the first few weeks of treatment, the foot is rigid with only a little movement. After use of two or three casts to correct the adduction deformity, the degree of subtalar motion increases and the foot becomes less rigid. When the adduction deformity is corrected, the calcaneal tuberosity will move laterally, the forefoot will no longer be adducted, and the heel varus will also be corrected.

However, even after the forefoot adduction and the heel varus are corrected, there will still be severe plantar flexion of all the metatarsals and severe equinus of the foot. Because the foot is short, stubby, and in a severe equinus position, it slips upward inside the cast, and the dorsum of the foot will become wedged at the ankle level of the cast (Figure 2a). To prevent the foot from slipping, the knee cast should be fixed at an angle of at least 110° (Figure 2b). During correction of the adduction deformity, the foot should not be abducted by more than 40° (Figure 2c) because if the Lisfranc joint is forced too much, it may subluxate. After correction of the forefoot adductus and heel varus by abducting the foot, unlike classical deformities, all the metatarsals are in plantar flexion position and the foot is in an increased equinus position in complex clubfoot. Correction of the equinus and metatarsal plantar flexion will occur simultaneously, and this will also

prevent cast slippage. The foot is grasped firmly with both hands and we apply pressure to the head of all metatarsals from the plantar surface of the foot. During this maneuver, an assistant should stabilize the knee (Figure 2d). It is also important that the foot abduction angle does not exceed 40° when the FAB is worn. Parents should be careful because there is also a high risk that the foot may slip within the cast, just as it could within the cast.

Statistical analysis

Statistical analysis was performed using the IBM SPSS for version 24.0 software (IBM Corp., Armonk, NY, USA). The normality of distribution of continuous variables was tested by Shaphiro-Wilk test. Freidman (for non-normal data) and Dunn's multiple comparison tests were used for comparison of numerical variables from three time points. Mann-Whitney U test was used to compare two groups for non-normal data. Descriptive statistic



FIGURE 2. Unilateral complex clubfoot deformity admitted 74 days after birth. (a) Foot shows severe equinus, a short hyperextended first toe, a plantar crease and a deep crease above heel. Foot is also edematous and erythematous. In accordance with modified Ponseti method, when casts are applied: (b) knee should be bent at an angle of at least 110° ; (c) forefoot adduction should not exceed 40° ; and (d) to correct metatarsal plantar flexion and foot equinus, clinician's thumbs are used to apply pressure to all metatarsal heads while an assistant stabilises patient's knee.

TABLE I
Pirani severity scores and ankle dorsiflexion measurements of patients whose treatment began at our institution and those referred from other institutions

	Not referred (n=9)			Referred (n=7)			<i>p</i>
	Mean±SD	Median	Min-Max	Mean±SD	Median	Min-Max	
Pirani, initial	5.1±0.49	0.5	4.5-6	5.4±0.6	5.5	4.5-6	0.408
Pirani after tenotomy	0.7±0.5	1	0-1.5	0.7±0.3	0.5	0.5-1	0.918
Pirani, final	0.4±0.5	0.5	0-1.5	0.4±0.4	0.5	0-1	0.681
Dorsiflexion before tenotomy	8.6°±3.7	10°	5-15°	8°±2.1	8°	5-11°	0.917
Dorsiflexion after tenotomy	15.3°±3.9	15°	10-20°	15°±3.8	15°	10-20°	0.918
Dorsiflexion, final	21.3°±5.0	22°	15-30°	18.7°±3.6	17°	14-23°	0.351

SD: Standard deviation.

parameters were presented as frequency, percentage (%) and mean ± standard deviation, median (min-max). A *p* value <0.05 was accepted as statistically significant.

RESULTS

The rate of complex deformity in the referred patients group was significantly higher (*p*<0.05). Five patients had bilateral clubfoot, whereas six had unilateral clubfoot (two right and four left feet). The mean follow-up duration was 13.3 (range, 10 to 16) months. A mean of seven (range, 5 to 8) casts were applied. After manipulation and casting, we performed Achilles tenotomies on all of the patients. In two of the referred patients, the Achilles tendons had been sectioned during the initial unsuccessful treatment attempt, and the ankle DF measurements were 8° and 10°. Therefore, a second Achilles tenotomy was performed on these two patients. No other patient had second tenotomy.

We observed relapses in three (18.8%) of our patients. Therefore, we applied two to three casts and all of the patients recovered. The posterior creases

disappeared from all 16 feet; however, the plantar creases persisted on two feet (12.5%). In one of these feet, the crease was very deep at the onset of treatment.

Among the referred patients, all seven affected feet showed signs of compression. There were sores on all of these feet, and five of them had erythema and edema. We waited for 7 to 10 days to allow the edema and erythema to subside before beginning the modified Ponseti casting procedure.

We compared the mean Pirani scores and ankle DF measurements of the patients whose treatment started at our institution (nine feet) with those referred from other centers (seven feet). We calculated the Pirani scores at the first visit, after tenotomy, and at the final visit. We recorded ankle DF measurements before tenotomy, after tenotomy, and at the final visit. There were no significant differences among the Pirani scores and DF measurements for any of the comparisons (*p*>0.05 for all comparisons, Table I).

Next, we considered the referred patients and our original patients together (Table II). The mean Pirani

TABLE II
Mean and median Pirani scores and ankle dorsiflexion angle measurements at first admission, after tenotomy and at final clinical visit

	n	Mean±SD	Median	Min-Max
Pirani, initial	16	5.2±0.5	5	4.5-6
Pirani after tenotomy	16	0.7±0.4	0.75	0-1.5
Pirani, final	16	0.4±0.4	0.5	0-1.5
Dorsiflexion before tenotomy	16	8.3°±3.0	8°	5-15°
Dorsiflexion after tenotomy	16	15.2°±3.8	15°	10-20°
Dorsiflexion, final	16	20.2°±4.5	21°	14-30°

SD: Standard deviation.

scores for all patients at the first clinical visit, after Achilles tenotomy, and at the final clinical visit were 5.2 ± 0.5 , 0.7 ± 0.4 , and 0.4 ± 0.4 , respectively. We compared the Pirani scores using Dunn's multiple comparison test and there were significant differences between after-Achilles tenotomy and first visit values, and the final visit and first visit values ($p=0.001$, $p=0.001$, respectively). However, there was no difference between the final visit and after-Achilles tenotomy values ($p=0.052$, Table II).

The mean ankle DF measurements for all patients before Achilles tenotomy, after Achilles tenotomy, and at the final clinical visit were $8.3^\circ \pm 3.0$, $15.2^\circ \pm 3.8$, and $20.2^\circ \pm 4.5$, respectively. We compared DF values using Dunn's multiple comparison test and there were significant differences between after-Achilles tenotomy and first visit values, the final visit and first visit values, and after-Achilles tenotomy and final visit values ($p=0.002$, $p=0.001$, and $p=0.022$, respectively; Table II).

DISCUSSION

Complex clubfoot is a subgroup of clubfoot and a congenital deformity. In our cohort, 11 of the 98 (11.2%) patients had complex clubfoot. Among patients who were treated at our institution from the start, we diagnosed six (7.7%) of 78 patients with complex clubfoot while five (25%) of patients referred from other centers had complex clubfoot. Referred patients had a higher risk of having complex clubfoot deformity. Detecting the risky patients earlier and applying the appropriate treatment method effectively prevented the treatment failure. All the deformities corrected successfully but needed a longer treatment period. The appearance of the feet and DF improved during FAB wearing period.

The clinician should be aware of complex clubfoot and continue treatment with the modified method in case of a complex case. Although the first steps of standard and modified methods are similar, it is more difficult to correct the adductus deformity in complex clubfoot deformity. Detecting the talar head is challenging and moving the calcaneus under the talus is harder than standard clubfoot deformity. It is critical to detect the talar head and increase the motion slowly in two or three manipulations and casting session for abduction of the foot. Another important difference in complex clubfoot is the increased equinus of the foot and metatarsal hyperflexion (Figure 2a). These deformities become more evident as we abduct the foot. If the clinician does not recognize these signs and fails to stabilize the knee at an angle of at least 110° , the cast will

slip and the dorsal surface of the foot will become compressed (Figure 1a, b). Abduction maneuver of the foot is also different from standard Ponseti. Clinician should not force the forefoot more than 40° of abduction. If the clinician forces the forefoot from 40° abduction to 70° , this may subluxate the foot at the Lisfranc joint and also compress it on the medial side. After we provide 40° of abduction and correct the heel varus, we correct the equinus deformity and metatarsal flexion with a special maneuver. We grasp the foot from the malleoli and at the same time apply pressure to the head of all metatarsals with both thumbs from the plantar surface of the foot (Figure 2d). This maneuver corrects equinus deformity and metatarsal hyperflexion at the same time. We stop the cast slippage by correcting the equinus and metatarsal hyperflexion. The Achilles tenotomy should be applied 1.5 cm above the posterior crease not to damage the posterior calcaneal tuberosity. After removing the cast, abduction angle of the FAB should be 40° , not 70° .

There is a controversy regarding whether the complex clubfoot is an iatrogenic or congenital condition. Ponseti et al.^[5] stated: We can draw no conclusions regarding whether the treatment failed owing to the feet or to the treatment. Dragoni et al.^[11] reported that faulty manipulation and a poor casting technique may convert a typical clubfoot into a complex iatrogenic deformity. Although we did not know the initial appearance and the treatment process of the referred patients, we followed-up patients whose treatment started at our institution. If a case of complex clubfoot was suspected, we followed it up carefully. By this way, we detected complex clubfoot in six patients. The characteristic appearance of complex clubfoot emerged after two or three casts. Because we applied the manipulation and casting carefully, there were no cast slippage or edematous and erythematous appearance. The first steps of the classical and modified Ponseti method are the same, thus we shifted to the modified method as we diagnosed complex clubfoot.

When the clubfoot deformity is complex, it is generally more rigid and requires a longer period of treatment. Ponseti et al.,^[5] Matar et al.,^[9] Dragoni et al.,^[11] and Mandlecha et al.^[10] reported that to treat complex clubfoot, a mean of five (range, 1 to 10), seven (range, 5 to 10), six (range, 4 to 8), and 7.44 (range, 6 to 10) casts were required, respectively. We applied a mean of seven (range, 5 to 8) casts. Ponseti et al.^[5] performed Achilles tenotomy on most of their patients. Previously treated patients were examined after manipulation and casting, and a

second Achilles tenotomy was performed on seven of 31 patients with ankle DF measurements of $<5^\circ$. Ponseti et al.^[5] noted that seven patients had relapses after successful treatment, and that three of these patients had a second Achilles tenotomy after relapse. Dragoni et al.^[11] treated a total of nine patients, performing Achilles tenotomy on four of them for the first time. Of the remaining patients, two had previous percutaneous tenotomy and three had previous Achilles tendon lengthening; Dragoni et al.^[11] repeated these same procedures. We performed Achilles tenotomy on all of our patients because they all had ankle DF measurements of $<10^\circ$. Two of the five patients who had previously been treated at another institution had previously undergone percutaneous tenotomy, and we performed a second tenotomy on these two patients. In total, three of our patients had relapses involving adduction deformities, and one of them also showed a decreased ankle DF. Following the application of a further two to three casts, all three patients recovered and did not need a second tenotomy or any other treatment.

Mandlecha et al.^[10] applied casts (mean 1.3; range, 0 to 4) following Achilles tenotomy, in case correction was incomplete. Matar et al.^[9] also reported that patients may require additional casts after tenotomy. Dragoni et al.^[11] did not apply any casts after tenotomy. In our study, we did not need any more casts after Achilles tenotomy because all ankle DF measurements exceeded 10° .

Because some of their patients were previously treated at other institutions, Ponseti et al.^[5] did not report Pirani scores. Mandlecha et al.^[10] reported that the mean Pirani scores at the treatment start time, first application of FAB, and final visit were 5.5741, 0.1852, and 0.0556, respectively. Pirani scores decreased as a result of effective treatment and careful follow-up procedure. Our results were similar and decreased throughout the follow-up period (Table II). Unlike Ponseti et al.^[5] we included the referred patients into the study because there were no significant differences between the initial Pirani scores of the patients who began their treatment at our institution and the referred patients (Table II).

Ponseti et al.^[5] recorded ankle DF measurements at the final visit. They reported that the mean ankle DF was 15° (range, 10 to 25°) and that the mean ankle DF for the seven patients who had a second tenotomy was 10° (range, 5 to 20°). In our study, we recorded ankle DF measurements before Achilles tenotomy, after Achilles tenotomy, and at the final visit. The DF measurements increased significantly after tenotomy and also increased between tenotomy and the final

visit (Table II). Ponseti et al.^[5] reported that the shape and length of the feet and the DF measurements improved over a period of several months. We made similar observations. After a successful treatment, the distinctive characteristics of a complex clubfoot (i.e. the puffy, short, and stubby appearance) gradually disappear.^[12] The increase in ankle DF is likely associated with these changes (Figure 1c, d).

Our study had some limitations. First, our follow-up period was short. We identified three cases of relapse and treated these patients with new casts and manipulation procedures. However, relapses can occur until the age of five years. Therefore, there will be more relapses in the future, and surgical procedures such as Achilles tendon lengthening and anterior tibialis tendon transfer will be needed. The only procedure performed during our follow-up period was Achilles tenotomy. Second, our patient population was very small due to the low incidence of complex clubfeet. However, we hope to study more patients and increase the duration of the follow-up period in our future studies. In addition, some patients were referred to our institution after initial treatment elsewhere, and this may have affected the homogeneity of our group of patients.

In conclusion, the modified Ponseti method is an effective treatment for complex clubfoot. Detecting the risky patients earlier and applying the appropriate treatment method effectively prevented the treatment failure. Referred patients had a higher risk of having complex clubfoot deformity. Classical clinical appearance, treatment-resistant deformities and referred patients should be warning signs for complex clubfoot.

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