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Radiological outcome of calcaneo-cuboid-cuneiform osteotomies for planovalgus feet in cerebral palsy children: Relationship with pedobarography

Rana El-Hilaly[a], Mostafa H. El-Sherbini[b], Mohamed M. Abd-Ella[c], Ahmed A. Omran[b,*]

[a] Department of Physical Medicine, Rheumatology and Rehabilitation, Faculty of Medicine, Ain-Shams University, Cairo, Egypt
[b] Department of Orthopaedic Surgery, National Institute of Neuromotor System (NINMS), GOTHI, Imbaba, Giza, Great Cairo, Egypt
[c] Department of Orthopaedic Surgery, Faculty of Medicine, Ain-Shams University, Cairo, Egypt

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ABSTRACT

Background: Calcaneo-cuboid-cuneiform (triple C) osteotomies correct all levels of deformity of flexible planovalgus feet (PVF) in patients with cerebral palsy (CP). The objective was assessing short term results and the hypothesis was that static pedobarography correlates with radiological parameters as outcome measures.
Methods: A prospective case series of consecutive skeletally immature ambulatory spastic CP patients above the age of 4 years who underwent triple C for PVF. Assessment was done using static pedobarography and standing dorsoplantar (DP) and lateral radiographs. The calcaneal pitch, lateral talocalcaneal, lateral and DP talo-first metatarsal, and DP talonavicular coverage angles were measured.
Results: Eighteen feet (12 patients) were analyzed. Postoperative changes in lateral and DP talo-first metatarsal, and DP talonavicular coverage angles were statistically significant (P-value = 0 with paired T-test). Post operative foot pressure changes were significant and highest in mid-foot. Both outcomes were related together with a p-value of 1 using McNemar test.
Conclusions: The triple C and associated soft tissue procedures reliably corrected PVF deformities. Static pedobarography can be used for postoperative assessment of adequate correction.

1. Introduction

Cerebral palsy (CP) is a major cause of childhood disability. Planovalgus foot (PVF) deformity is commonly encountered in CP patients. Although in the normal population flexible flatfoot is considered a normal variant, this is not the situation in CP where children with PVF will have a progressive deformity that frequently leads to foot pain, and gait compromise [1]. In a population study, feet were the most common reported site of pain in CP children; particularly in good ambulators [2]. Several studies confirmed that PVF deformity whether neuromuscular or idiopathic will reduce ankle and midfoot power, with additional increased midfoot dorsiflexion mobility in CP [3–5]. This will reduce stance phase stability and ankle plantar flexion power in CP children, leading to lever-arm dysfunction. It will manifest as short step length, and progressive knee flexion. The gait disturbance may progress into crouch gait [6,7,8,9].

Surgery is indicated with symptomatic and/or progressive deformity. As the deformity is usually flexible, variable osteotomy techniques were described [10,11]. The calcaneo-cuboid-cuneiform osteotomies (triple C) were recommended as a method that permits correction at all levels of deformity (hind, mid and forefoot), and thus is more versatile [12–14].

Radiological outcomes are the mainstay for assessing postoperative changes [15,16]. Pedobarography (plantar pressure measurement) is increasingly used as an adjunct assessment method for postoperative changes. It is a computerized image of the part of the sole in contact with the ground, providing data on pressure under different foot areas, and the area of contact. It can be static or dynamic [17–20]. Most of the literature reporting on normal values and radiological correlations was on dynamic pedobarography [18,20,21].

The first objective of this study was evaluating the radiological and static pedobarographic outcomes of triple-C osteotomies for correction of flexible planovalgus feet in CP children on the short-term. The second objective was identifying relationships between radiological angles and pedobarography. By drawing these relationships we aimed at deciding whether static pedobarography is an appropriate postoperative outcome measure.

* Corresponding author.
E-mail address: pedorthoconsult@zoho.com (A.A. Omran).

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2. Methods

2.1. Study design

This study was a prospective case series of consecutive CP children who underwent triple C foot osteotomies whether in isolation or as part of single event multilevel surgeries (SEMLS). Static pedobarography, and standing radiographs were done preoperatively and postoperatively. *Inclusion criteria* were ambulatory children and adolescents (GMFCS I–IV) with PVF deformity, midfoot break and prominent talar head. The deformity was flexible, symptomatic and progressive despite a trial of bracing for at least a year. Symptoms were either local as foot pain and callosities leading to difficulty with foot wear and orthotics, or general affecting the child gait due to lever-arm dysfunction. *Exclusion criteria* were children younger than 4 years of age, skeletal maturity, rigid deformity and non-ambulatory (GMFCS V) patients. Between May 2016 and April 2017, 18 feet (12 patients) underwent triple C osteotomies and had both pedobarography and radiology done.

The study was conducted in a tertiary institute. Institutional review board approval was acquired.

2.2. Surgical technique

The triple C procedure [14] involved 3 osteotomies. A medial displacement calcaneal osteotomy (MDCO) fixed with 2 k-wires, an open wedge cuboid osteotomy with a tricortical bone graft, and a plantar based medial cuneiform closed wedge. The medial and lateral columns were fixed respectively each with a k-wire. For equinus deformity, Vulpius type gastrocnemius recession was done in Silfverskiold positive test. Peroneus brevis surgery and medial column soft tissue procedures (talonavicular reduction with capsular and tibialis posterior plication) were initially done at the discretion of the operating surgeon. However, later in the study we decided on performing both routinely.

2.3. Rehabilitation

After cast removal patients were kept in day time ankle-foot-orthosis for 3 months. Patients with crouch gait were kept in ground-reaction-foot-orthosis. Regular physiotherapy was done including muscle stretching and strengthening, range of motion, standing and gait training.

2.4. Outcome measures

2.4.1. Radiographic assessment

Standing dorsoplantar (DP) and lateral radiographs were done. Measured angles were calcaneal pitch (CP), lateral talocalcaneal (Lat-TC), lateral talo-first metatarsal (Lat-T1st), DP talonavicular coverage (DP-TN), and DP talo-first metatarsal (DP-T1st). Landmarks and normal population values as proposed by Davids et al. [15] were used. The CP angle was measured between a line joining the lowermost point of calcaneal tuberosity and the lowermost point of calcaneo-cuboid joint. The Lat-T1st and DP-T1st angles measured between the long axis of first metatarsal and talar axis. The DP-TN angle was measured between a line along the margins of navicular articular surface and a line along the margins of talar head articular surface.

2.4.2. Plantar pressure assessment (pedobarography)

The Matscan (Tekscan Inc., vers. 6.34, Boston, USA) was used. Readings for average pressure were taken in static condition (standing). Following the manufacturer's instructions calibration was completed with subjects standing on the Matscan to minimize errors. Tests were repeated and the most representative reported. Pressure mapping was divided into five metatarsal (M) areas, M1 to M5 denoting first to fifth metatarsal, two mid-foot areas (medial and lateral), and two heel areas (medial and lateral).

2.5. Statistical analysis

IBM SPSS statistics (V. 24.0, IBM Corp., USA, 2016) was used for data analysis. Data were expressed as (Mean ± SD) for quantitative parametric measures in addition to median and percentiles for quantitative non-parametric measures and both number and percentage for categorized data.

For parametric data comparison between 2 dependent groups was done using Paired t test. The level of significance was set at 0.05, while at 0.01 and 0.001 as highly significant. For categorical data comparison between 2 dependent groups was done using McNemar test and binomial distribution.

3. Results

3.1. Population

The population included 18 feet in 12 patients (6 patients were bilateral). The mean *age* was 9.7 years (SD = 3.46, range 5.1–15.3 years). Average follow-up was 17 weeks (range 10–26 weeks). Patient characteristics and GMFCS status are reported in Table 1.

3.2. Procedures

All feet underwent triple C osteotomies using the technique described above. Equinus was corrected in 9/18 feet (50%) either at the time of index or within one year earlier. Foot procedures are detailed in (Table 2). Isolated foot and ankle procedures were performed in 4/18 feet (22.2%), where in 14/18 feet (77.8%) SEMLS was done (Table 3).

Table 1
Demographic data for patients and feet.

Variable		Patients (total 12)	Feet (total 18)
Sex	Male	7 (58.3%)	10
	Female	5 (41.7%)	8
Side	Bilateral	6 (50%)	
	Rt	4 (33.3%)	10
	Lt	2 (16.7%)	8
GMFCS	GMFCS I	1 (8.3%)	1
	GMFCS II	2 (16.7%)	2
	GMFCS III	3 (25%)	5
	GMFCS IV	6 (50%)	10

Table 2
Foot and ankle procedures.

Procedure		Feet (total 18)
Equinus correction (gastrocnemius)	Concomitant	6
	Previous	3
	None	9 (50%)
Peroneus brevis surgery	Yes	15 (83.3%)
	No	3 (16.7%)
Medial procedure	Yes	13 (72.2%)
	No	5 (27.8%)

Table 3
Other procedures.

Procedure	No.
Supracondylar extension osteotomy	3
Supracondylar derotation osteotomy	9
Tibial derotation osteotomy	4
Hamstring lengthening	2
Patellar tendon plication	4

3.3. Radiological

All 18 feet had weight bearing DP and 16 feet had weight bearing lateral views (Figs. 1–3). Radiological angles were described as mean, range and standard deviation (SD).

Postoperative changes were significant for lat-T1st, DP-TN and DP-T1st as measured by paired T-test (Table 4). Angles were further analyzed according to whether the absolute value was considered acceptable or not. If the angle was less than or equal to a cut-off value (normal population mean + 2SD) it was deemed acceptable (Fig. 6). Analysis was done comparing the number of feet with acceptable angle value postoperative as compared to preoperative. Again, only changes of lat-T1st, DP-TN and DP-T1st angles were significant using McNemar test (Table 5).

Regarding inadequate correction if we use the mean + 2SD as a cut-off value, then we will have 1/16 feet (6.2%) for lat-T1st, 1/18 feet (5.6%) for DP-TN, and 2/18 feet (11.1%) for DP-T1st. If we use the mean + 1SD as a cut-off value, then we will have 1/16 feet (6.2%) for lat-T1st, 5/18 feet (27.8%) for DP-TN, and 4/18 feet (22.2%) for DP-T1st.

3.4. Pedobarography

Foot pressure (Fig. 4) was measured both as absolute pressure of each area, as the difference between medial and lateral pressures (medial and lateral heel, medial and lateral midfoot, and between M1 and M5 in the metatarsal area).

Postoperative changes in absolute pressure were measured with paired t-test. P-values were lateral heel = 0.008, midfoot medial and lateral = 0.002, M1 = 0.039 and M5 = 0.008. Thus there were significant changes in all areas with lowest p-value for midfoot areas.

Postoperative change in medial/lateral difference was described in two ways. First, whether the variable improved or not, where improved is an increase in lateral pressure or a decrease in medial pressure (Fig. 5). Second, whether the measured variable was acceptable (Y) or not (N). A value where lateral pressure equals or more than medial pressure was considered acceptable (Fig. 6). There were statistically significant postoperative changes in all areas (value changing from non acceptable preoperatively to acceptable) using McNemar test. Mid-foot difference, p-value = 0, heel difference, p-value = 0.001, metatarsal difference, p-value = 0.016.

3.5. Radiologic-Pedobarographic relationship

To analyze relation between postoperative changes in foot pressure and angles (as Y/N) we measured p-value with McNemar test where a significant value (<0.05) means the 2 groups are independent (not related to each other). The higher the p-value means that the 2 groups are related together and the null hypothesis could not be rejected. The p-value was highest with a value of 1 between midfoot pressure changes and changes in lat-T1st, DP-TN and DP-T1st angles (Table 6). Furthermore, using the absolute values, the spearman correlation coefficient was significant between midfoot postoperative difference and both DP-TN and AP-T1st angles (correlation coefficient = 0.64, and p-value = 0.004).

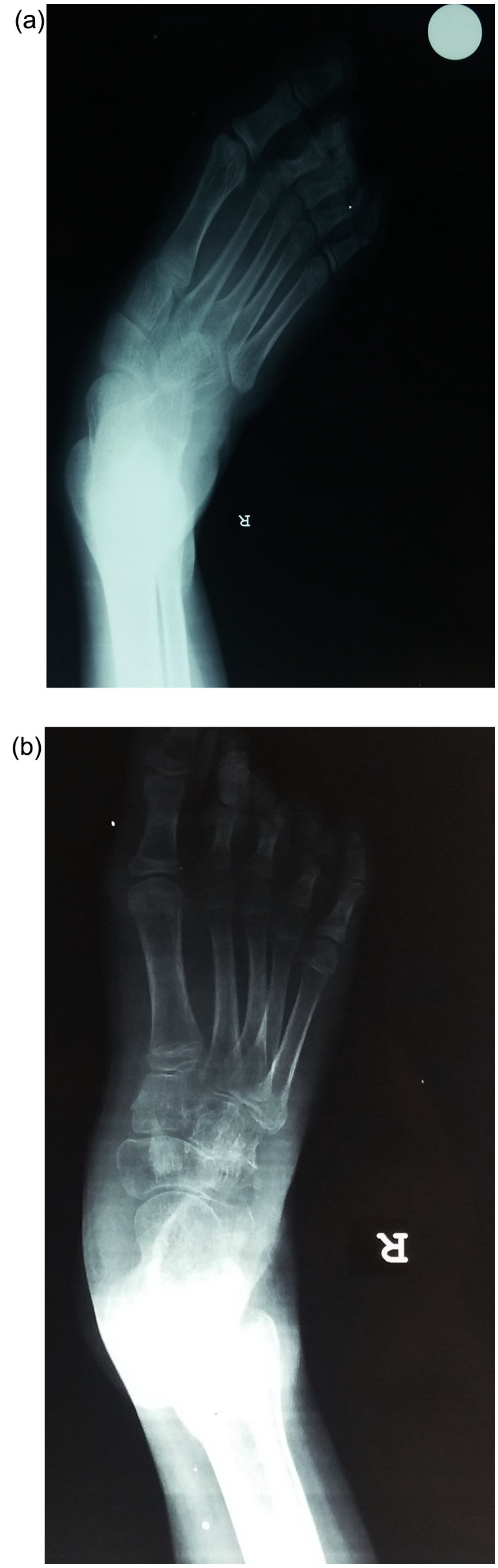

Fig. 1. Standing dorsoplantar view pre and postoperative. (a) Preoperative. (b) Postoperative 2.5 months.

Fig. 2. Standing lat view of the same foot pre and postoperative. (a) Preoperative. (b) Postoperative 2.5 months.

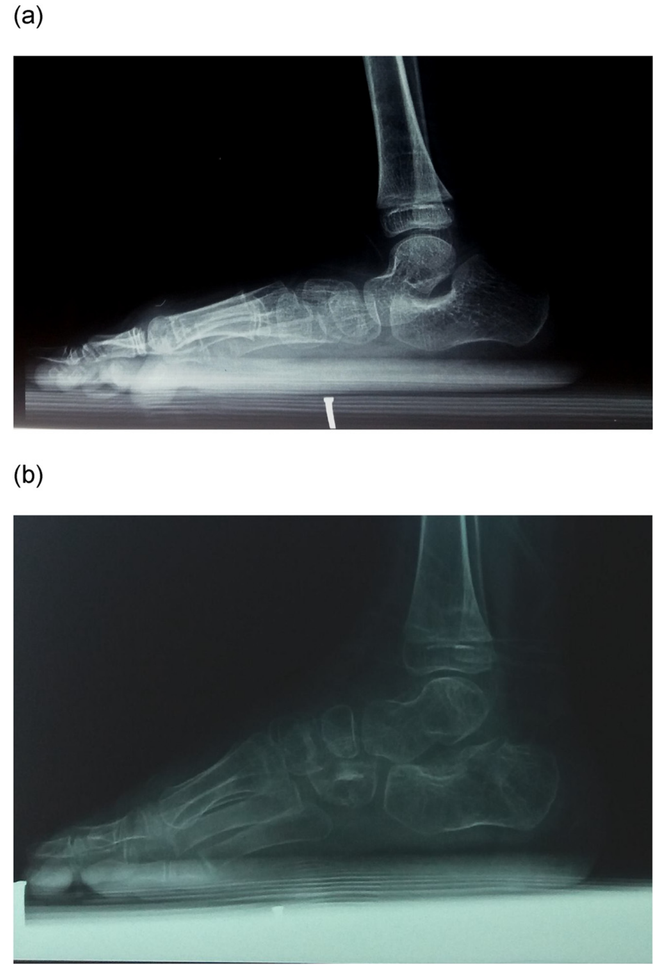

Fig. 3. Standing lateral view of another patient pre and postoperative. (a) Preoperative. (b) Postoperative 4 months.

4. Discussion

There is a consensus that PVF deformity in CP will most likely progress and become symptomatic, yet a prolonged trial of conservative measures is advocated [1]. The deformity will not just cause local symptoms but also “lever arm dysfunction”. This term refers to hip instability, torsional long bone and foot deformities occurring in spastic CP. These angled or flexible bony levers reduce the effectiveness of muscle action and gait [22]. There is no best surgical technique described in literature. In the early 90s Mosca popularized lateral calcaneal lengthening (LCL) reporting satisfactory results in both mild and severe deformities. In 1998 triple C osteotomies were reported. Kim et al. suggested triple C offered greater degree of correction than LCL [12]. However, Moraleda et al found that LCL was more effective in the correction of forefoot abduction [13]

In plain radiographs the complex malalignment of PVF includes hindfoot valgus, collapse of the medial longitudinal arch with plantar flexed talus, and abduction through the midfoot with dorsolateral subluxation of the navicular on the talus [16,23]. In our study there was a significant decrease in the DP talo-first-metatarsal, the DP talonavicular and the lateral talo-first-metatarsal angles reflecting a decrease in planus and forefoot abduction deformity. Changes in calcaneal pitch and lateral talocalcaneal angle were not statistically significant. These results are similar to those previously reported [13,24].

Using the mean + 1SD as a cut-off value, undercorrection was only 6.3% in the lat-T1st and 22.2% in the DP-T1st angles. The low undercorrection rate despite a low cut-off value, as compared to literature may be related to the additional medial soft tissue procedures [24].

Plantar pressure measurement systems (pedobarography) offer a portable instrument that provides information on pressures applied to specific foot areas. It can be used as an evaluation tool to measure the severity of varus and valgus foot deformity, and the effect of surgery [1,18,25,26]. For dynamic pedobarography, average normal values in children were reported [18,21]. A study

Table 4
Overall mean and change in radiological angles.

	N	Mean	SD	T	p	Sig
Calcaneal pitch (preop)	16	6.73	8.293			
Postoperative	16	9.2	8.703	−0.703	0.494	NS
Lat talocalcaneal (preop)	16	45.88	11.477			
Postoperative	16	37.94	10.234	1.967	0.068	NS
Lat talo-first metatarsal (preop)	16	28.5	10.386			
Postoperative	16	9.63	7.796	5.979	0	HS
DP talonavicular coverage (preop)	18	56.72	9.688			
Postoperative	18	14.67	25.114	6.675	0	HS
DP talo-first metatarsal (preop)	18	36.28	11.187			
Postoperative	18	2.61	22.419	5.16	0	HS

P value measured by paired T-test. preop = preoperative.

Table 5
Radiological outcome with cut-off value = population mean + 2SD.

	Angle CP		Angle lat-TC		Angle lat-T1st		Angle DP-TN		Angle DP-T1st 5	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Y	11	10	15	15	7	15	1	17	1	16
%	68.8%	62.5%	93.8%	93.8%	43.8%	93.8%	5.6%	94.4%	5.6%	88.9%
N	5	6	1	1	9	1	17	1	17	2
%	31.2%	37.5%	6.2%	6.2%	56.2%	6.2%	94.4%	5.6%	94.4%	11.1%
Total	16	16	16	16	16	16	18	18	18	18
P-value		1.0		1.0		0.008		0		0

Y = acceptable with angle less or equal to cut-off value. N = not acceptable with angle more than cut-off value. P-value measured with McNemar test, p-value < 0.05 is significant.

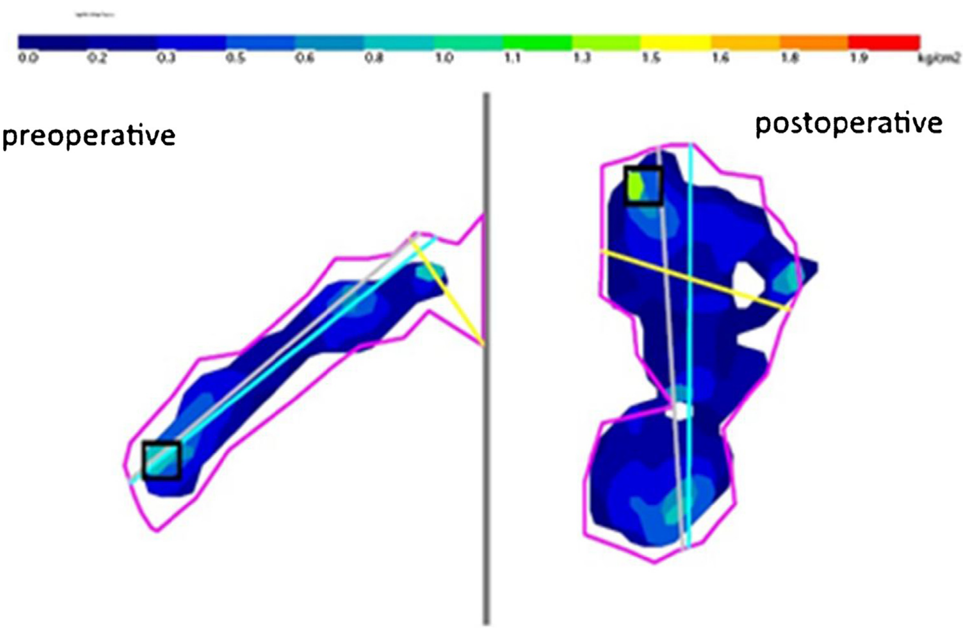

Fig. 4. Static pedobarography of the same foot shown in Fig. 1.

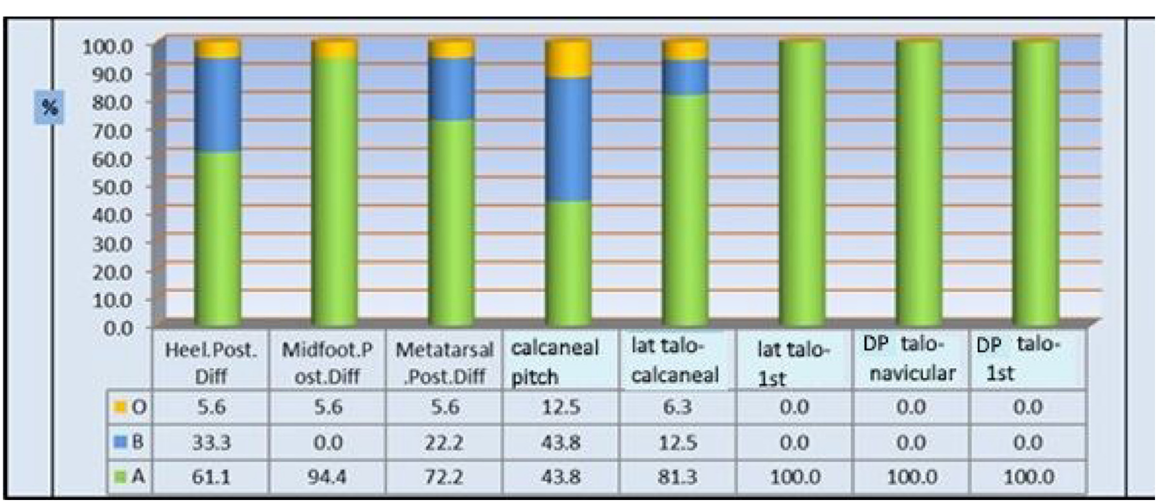

Fig. 5. Postoperative changes in radiological and pedobarographic variables as improved or not.
A = improved, B = worse, O = no change. Foot pressure is expressed as "post.diff" = postoperative difference between medial and lateral pressure where improved is an increase in lateral to medial pressure difference (see text for details). For radiological angles, improved is a postoperative increase in calcaneal pitch and an increase in the other four angles.

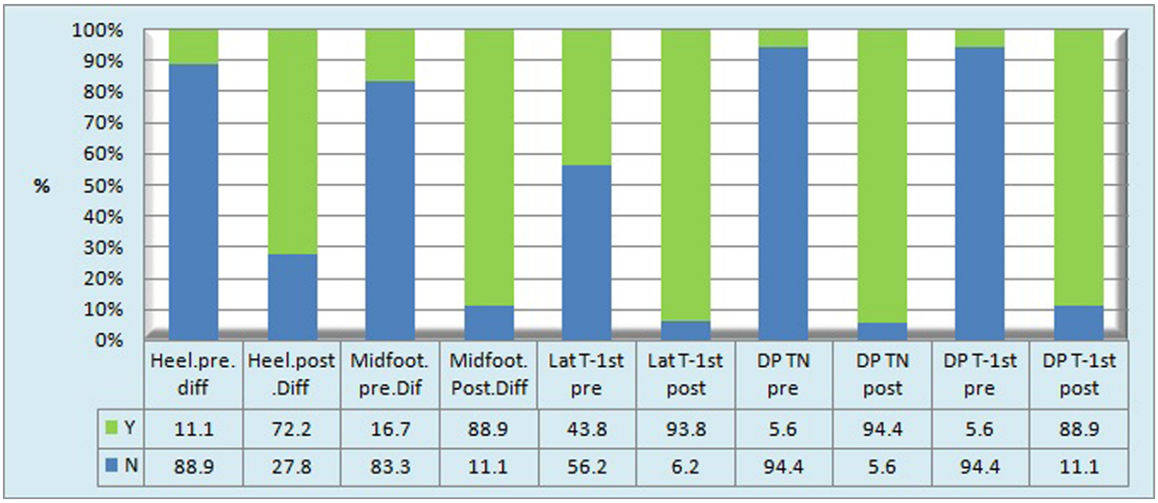

Fig. 6. Pedobarographic and radiological variables as acceptable or not.
Y = acceptable and N = not acceptable. Cut-off value for foot pressure is lateral ≥ medial, and for radiological angles ≤ population mean + 2SD.
Diff: difference. T-1st: talo first metatarsal angle, TN: talonavicular angle.

Table 6
Relationship between changes in radiological angles and changes in foot pressure.

Change	Heel diff	Mid-foot diff	Metatarsal diff
Lateral talo-first metatarsal	0.375	1.000	0.008
DP talonavicular	0.219	1.000	0.004
DP talo-first metatarsal	0.375	1.000	0.008

P-value measured with McNemar test. The higher the p-value, the greater the relationship is. Diff = difference between medial and lateral pressure areas.

on CP patients confirmed both intra and inter-observer reliability [20]. For static pedobarography, there are no available average population values of absolute peak pressure which is affected by weight and foot size among other variables [17].

It was documented that as children start to walk there is a flatfoot pattern manifested by early and high medial midfoot loading that gradually changes for a heel to forefoot pattern with marked decrease in medial midfoot loading by the age of 5 years [21,27]. Regarding dynamic foot pressure changes in PVF feet, several consistent patterns were reported, including increased medial midfoot, and decreased lateral midfoot pressure [18,28]

Correlations between dynamic pedobarography and radiological angles were previously reported. One study reported relationship between DP talonavicular uncoverage and medial midfoot pressure [18]. Another found that pressure changes in midfoot areas were correlated with both DP and Lat talo-first metatarsal angles [29]. Dynamic pedobarography poses two problems. One is difficulty in contacting the platform because of coordination and balance problems. Another is “targeting” where the patient alters his walking pattern to manage placing the foot in contact with the platform [25,30,31]. In our study only static measurements were done. The poor ambulatory status and difficulty in communication with most patients made it difficult for us to obtain dynamic pedobarography using our mat system. This could have been more feasible with insole sensors or long walkways. We found a statistically significant change postoperatively in the pressure values of the lateral mid-foot as compared to the medial mid-foot reflecting an increase in lateral loading of the foot. These changes were significant and matched changes in lat-T1st, DP-TN and DP-T1st angles confirming earlier reports. Heel pressure values also improved but neither the changes nor the relationship with radiological values were consistent as in midfoot.

Most orthopaedic CP studies are retrospective with poor bias control. Hence the insufficient generalization and validity of results are major shortcomings [32]. Our patients were enrolled prospectively with predefined inclusion criteria. This can put strength to our study.

Weaknesses of the study include small patient population, and SEMLS which results in confounding variables. Furthermore, we did not report on clinical and functional outcomes because of the short follow-up, However, we believe this short duration had no effect on the reported relationship between radiological and pedobarographic outcomes as both were measured at the same follow-up.

5. Conclusion

The triple C osteotomies with associated soft tissue procedures reliably corrected the PVF deformities. Postoperative changes in foot pressure were highly significant in the mid-foot and to a lesser extent the heel and metatarsal areas. Postoperative changes in radiological angles were significant in the lat and DP talo-first-metatarsal angles, and in the DP talonavicular coverage. Changes in the three angles and mid-foot pressure were related together. Static pedobarography can be used as a postoperative outcome measure for flexible PVF correction in CP patients.

Conflict of interest

None.

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