Double-column foot osteotomy to correct flexible valgus foot deformity in children with spastic cerebral palsy

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Background
Mobile (flexible or correctable) hindfoot valgus deformity is common in children with spastic cerebral palsy (CP). It is accompanied by short lateral and long medial foot column.

Patients and methods
Eleven ambulatory children (20 feet) having spastic CP (two hemiplegic and nine diplegic) and presenting with mobile (flexible) hindfoot valgus deformity were evaluated neurologically, orthopedically, and radiographically and operated upon in the National Institute of Neuromotor System between September 2012 and September 2013. Double-column foot osteotomy with medial cuneiform closing-wedge resection and cuboid opening-wedge resection without attacking the calcaneus was performed in all of them.

Results
The results were followed up clinically and radiographically over a period ranging from a year and a half (18 months) to 2 years (24 months), with an average of a year and 9 months (21 months), and were graded into four categories as excellent, good, fair, and poor according to the total calculated score. According to the suggested grading system, there were eight excellent results, eight good results, four fair results, and no poor results.

Conclusion
Double-column foot osteotomy shortening the medial foot column and lengthening the lateral foot column to correct moderate to severe hindfoot valgus in ambulatory children with spastic CP compared favorably with similar series and offered option for achieving foot alignment, improving pain and skin problems, and avoiding the problems associated with arthrodesis.
Level of evidence: the study is type IV therapeutic level of evidence.

Keywords:
flexible pes valgus, mobile valgus foot, spastic cerebral palsy

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Introduction

Mobile (flexible or correctable) hindfoot valgus deformity is common in children with spastic cerebral palsy (CP). In ambulatory children, the foot progresses into more valgus by standing. The talar head becomes more prominent and the medial longitudinal arch collapses, making the orthosis difficult and even painful with possible skin problems.

Attempts to correct these deformities by lateral foot column lengthening through calcaneal osteotomy and iliac bone graft [1–3] may not be sufficient alone, as shortening osteotomy of the medial column may be necessary for complete correction. In addition, the calcaneal osteotomy may injure the subtalar joint (STJ) in some cases owing to anatomic variation, and the iliac bone graft may be cumbersome. Fusion of one or multiple joints [4] may be followed by resorption or failure of the graft, nonunion (pseudoarthrosis), loss of STJ motion [5,6], and vulnerability to skin ulceration of the rigid foot.

The aim of the work was to establish a protocol for diagnosis and treatment of paralytic mobile (flexible or correctable) subtalar hindfoot valgus deformity in ambulatory children with spastic CP and to evaluate the results of the double-column osteotomy of the spastic foot in correction of the foot deformity, foot pain relief, STJ mobility, tolerability to orthoses, and overall patient/parent satisfaction.

Patients and methods

Eleven consecutive ambulatory children (20 feet) having spastic CP (two hemiplegic and nine diplegic) and presenting with mobile (flexible) hindfoot valgus deformity were operated upon in the National Institute of Neuromotor System between

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September 2012 and September 2013 in this study. The study was approved by the institutional ethics committee in the Department of Orthopaedics, Cairo University, Cairo, Egypt.

Inclusion criteria

Moderate (15–20°) to severe (20° or more) mobile (flexible) hindfoot valgus deformity, in ambulatory children with spastic CP [Gross Motor Function Classification System (GMFCS) 1–2), with no neurological deficits as incoordination or involuntary movements, between 6 and 7 years of age, were chosen.

Exclusion criteria

Fixed (rigid) hindfoot valgus deformity as that of vertical talus, arthrogryposis, and tarsal coalition; other neurological disorders than spastic CP; nonambulatory children with spastic CP (GMFCS >2) or with neurological deficits as incoordination or involuntary movements; those with idiopathic pes valgus; and children below 6 years or above 7 years of age were rejected.

The average age at the time of surgery was 6 years and 8 months (range, 6–7 years of age). Five patients (nine feet) were at the age group of 6 to less than 6½, and six patients (11 feet) at the age group of 6½ to less than 7. There were six male patients (or boys), where five of them had both feet affection, that is, diplegic, and one had only right foot affection, that is, right-sided hemiplegic, and five were female patients (or girls), where four of them had both feet affection, that is, diplegic, and one had only left foot affection, that is, left-sided hemiplegic.

All of them underwent double-column foot osteotomy. Among them, there were four boys and two girls who underwent Achilles' tendon lengthening (ATL), each in both feet, and there were two boys (one of them in both feet and one in the left foot) and two girls (one of them in both feet and one in the right foot) who underwent peroneal tendon lengthening. The right foot was operated upon in six patients (all males, five of them bilateral, i.e. in 10 feet), and the left foot was operated upon in five patients (all females, four of them bilateral, i.e. in 10 feet) (Table 1).

History, original disease, examination, and treatment

All of the 11 patients had history of difficult delivery and were incubated at birth. Nine were spastic diplegic, and two were spastic hemiplegic (one right-sided and one left-sided), but no patient was of the total body involvement type. Each of them received some forms of nonoperative treatments such as physical therapy programs, orthoses, and skeletal muscle relaxant but no previous surgery.

Presentation complaints

(1) Foot pain
Frank foot pain (in eight cases) or discomfort (in 12 cases) was experienced. Pain was particularly over the bony prominence (talar head).
(2) Foot deformity
All the patients (or parents) were annoyed of the outwardly deviated shape of their (or their children's) feet, which were not tolerating any form of shoes or orthoses.
(3) Skin problems
Pressure sores or ulcerations by shoes or orthoses were noticed in progressive deformities.

Preoperative assessment

(1) Clinical assessment
  (a) Neurological assessment
  Neurological examination showed that all patients had spastic CP, of which two patients were hemiplegic and nine patients were diplegic. Assessment implied detecting spasticity (hypertonia), eliciting of exaggerated deep reflexes, positive Babinski sign, and exclusion of incoordination and involuntary movements.
  (b) Orthopedic assessment
  Orthopedic examination implied the gait, spastic muscle grading, the presence of deformities other than that of the foot, and the weight-bearing alignment of the hindfoot.
  Foot deformity
  Outward deviation of the foot with prominent head of talus (i.e. hindfoot valgus) ranging from moderate (15–<20°) to severe (20° or more), and collapsed medial longitudinal arch (examined by Jack's test) [7] were present in all cases. Two patients (four feet) had severe (20° or more) hindfoot valgus deformity, whereas the remaining nine patients (16 feet) had moderate (15–< 20°) deformity. All feet were sufficiently mobile (flexible or correctable) to normal alignment. Associated tight Achilles' tendon, but without ankle equinus deformity (in 12 cases; examined by limited ankle dorsiflexion with the knee straight and/or flexed, i.e., Silfverskiold test) [7], and prominent spastic peroneal tendons (in six cases) were evident. From the history, progression of the deformity occurred in all

Table 1 Classification of patients in relation to their sex, foot side, and surgery performed

Operation	Males (boys)			Females (girls)			Total cases (feet)
Double-column foot osteotomy		6			5		20
	Right	Left	Bilateral	Right	Left	Bilateral	
	1	0	5	0	1	4	
Achilles' tendon lengthening		4			2		12
	Right	Left	Bilateral	Right	Left	Bilateral	
	0	0	4	0	0	2	
Peroneal tendon lengthening		2			2		6
	Right	Left	Bilateral	Right	Left	Bilateral	
	0	1	1	1	0	1	

Table 2 Grading of the spastic muscles around the foot of all cases

Case number	EHL	EDL	TA	TP	PL and B	FHL	FDL	TS
1	4	4	2	2	4	4	4	4
2	4	4	2	2	2	2	0	4
3	4	4	2	2	2	2	2	4
4	3	3	3	3	3	3	3	3
5	4	4	3	3	3	4	4	4
6	4	4	4	4	4	4	4	4
7	4	4	4	4	4	4	4	4
8	4	4	4	4	4	3	3	5
9	3	3	4	4	4	3	3	3
10	3	3	2	2	2	3	3	3
11	4	4	2	2	2	2	4	4
12	3	3	2	2	4	3	3	3
13	3	3	0	0	4	3	3	3
14	5	5	2	2	4	5	5	5
15	4	4	2	2	5	5	5	5
16	4	5	2	2	2	5	5	5
17	4	4	5	5	5	4	4	4
18	5	5	4	4	4	5	5	5
19	4	4	4	4	4	4	4	4
20	4	4	2	2	5	4	4	4

EDL, extensor digitorum longus; EHL, extensor hallucis longus; FDL, flexor digitorum longus; FHL, flexor hallucis longus; PL & B, peroneus longus and brevis; TA, tibialis anterior; TP, tibialis posterior; TS, triceps surae.

patients with repeated change of shoes or orthoses.

Functional disabilities:

All were able to walk without support and were considered to be community-level ambulatory with GMFCS of level 1–2 before foot surgery. They had variable active power around the ankles and feet (Table 2). Fourteen cases had no imbalance between the peronei and the tibialis anterior and posterior muscles. Six cases had powerful peronei versus tibialis anterior and posterior muscles.

(2) Radiographic assessment

Weight-bearing anteroposterior and lateral radiographic views of ankles and feet were taken for all patients. Ankle anteroposterior radiography excluded the possibility of valgus at the talotibial joint evidenced by talar tilt in the ankle mortise [8]. In the anteroposterior view of the foot, the anterior talocalcaneal angle (TCA_1) or Kite's angle, talonavicular angle (TNA), talonavicular coverage angle (TNCA), and anterior talo-first metatarsal angle ($TFMA_1$) were measured. In the lateral view of the foot, the lateral talocalcaneal angle (TCA_2) and the lateral talo-first metatarsal angle ($TFMA_2$) or Meary's angle were measured.

All patients had shown failure of conservative measures and ankle-foot orthoses treatment for at least 6 months before surgery. Four patients (seven cases) had difficulty in maintaining stability while walking. Six patients (11 cases) developed progressive deformity with collapsed medial longitudinal arch. Four patients (six cases) developed footwear or orthotic intolerance and skin problems.

Operative procedure

Double-column foot osteotomy with medial cuneiform closing-wedge resection and cuboid opening-wedge resection without attacking the calcaneus was performed in all of the 11 patients (20 feet).

The procedure was done under general anesthesia, and the patient was supine. A tourniquet was applied in the upper thigh. Skin was prepared and limb draped, with the knee on view to provide orientation to rotational alignment.

Skin incisions

The skin was incised through two skin incisions, a longitudinal medial one over the medial cuneiform exposing it, and longitudinal lateral one along the cuboid exposing it, anterior and parallel to the peroneal tendons (Fig. 1). Care was taken in the medial incision to avoid injury of the tibialis anterior tendon and the long saphenous vein. The lateral incision was extended following Langer's skin lines, below and behind the lateral malleolus (Ollier's) in cases of peroneal tendon lengthening. Care was taken to avoid injury of the sural nerve and the short saphenous vein which were carefully retracted. An additional posteromedial skin incision parallel to Achilles' tendon was made in cases of ATL.

Soft-tissue (tendons) procedures

Peroneal tendon lengthening and ATL were performed, according to the circumstances of the case, in the same session, but before the bony procedures.

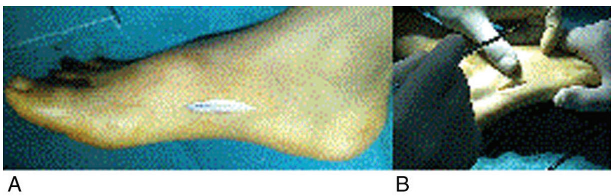
Peroneal tendon lengthening:

Through extension of the lateral skin incision, a sagittal plane longitudinal split in the peroneal tendons was performed in cases of severely spastic peronei functioning as a deforming element (six cases).

Achilles' tendon lengthening

A Z-plasty of the tendinous part was performed in cases associated with tight Achilles' tendon (12 cases). The tendon was split longitudinally in the sagittal plane and divided at its distal end laterally and its proximal end medially into two longitudinal halves. The lateral distal cut was to eliminate the tendon pull laterally on the hindfoot. The deformity was corrected till the foot was plantigrade (tibiocalcaneal angle 90°) with the knee fully extended to prevent postoperative deformity in the opposite calcaneal position.

Figure 1



Skin incisions: (a) medial and (b) lateral.

Bony procedures

Medial cuneiform closing-wedge resection

The middle third (i.e. central portion) of the medial cuneiform was removed by a fine sharp osteotome (or even a scalpel in some cases with softer bones), with its base plantarward to allow its later closing wedge in adduction and plantar direction recreating a medial longitudinal arch [9] (Fig. 2).

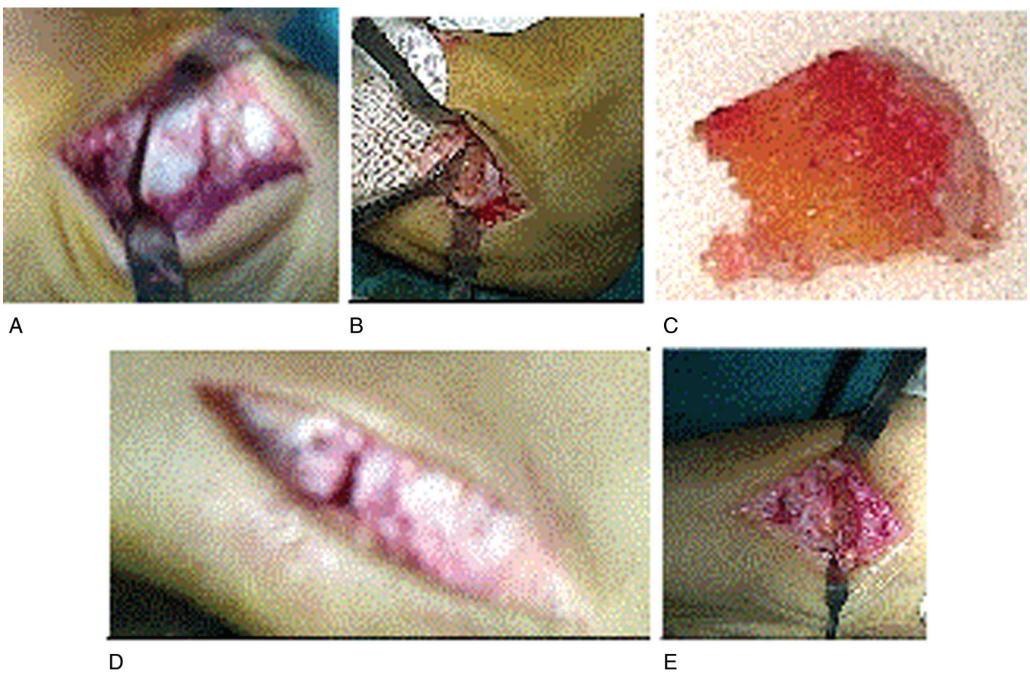
Cuboid opening-wedge osteotomy

An osteotomy was made in the cuboid, opening a wedge in it according to the predetermined amount and distracting it in position by a suitable osteotome or a laminar spreader (Fig. 3). An intraoperative ruler measured the base length of the wedge, comparing it with the predetermined one, overcorrecting the foot deformity [6].

Graft insertion

The wedge graft taken from the medial cuneiform was inserted in the cuboid open-wedge osteotomy, increasing the length of the foot lateral column and correcting the pes valgus deformity [6] (Fig. 4).

Figure 2



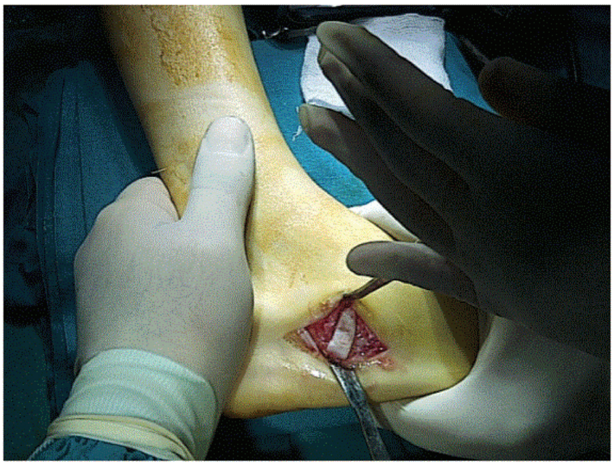
(a) Medial cuneiform wedge osteotomy, (b) wedge resection, (c) the wedge, (d) plantarward wedge base, and (e) after wedge resection.

An intraoperative C-arm image would be helpful to assess the corrected foot position in two planes: anteroposterior and lateral (Fig. 5).

Figure 3

Cuboid osteotomy.

Figure 4



The wedge graft taken from the medial cuneiform and inserted in the cuboid open-wedge osteotomy.

K-wire fixation

The cuboid opening wedge and the graft were pinned percutaneously by 1.6-mm K-wires.

Closure

All wounds were closed in layers. The skin was closed by interrupted or subcuticular 0/3 vicryl sutures. The K-wires were bent 90° and left out through the skin.

Immobilization POP cast and postoperative care

A well-molded nonweight-bearing below-knee plaster of paris (POP) cast was applied in almost all cases, except for 12 cases in which an above-knee POP cast was applied for ATL. The K-wires and the interrupted skin sutures were removed at the time of cast change after 6 weeks. The period of immobilization was 8 weeks for all cases.

Postoperative assessment and follow-up regime

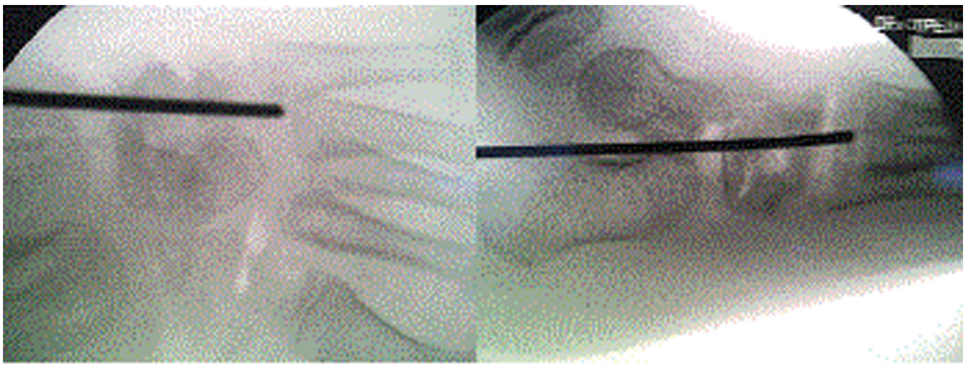
After cast removal, at least 6-week interval of gait training physiotherapy was instructed to all cases. A follow-up period ranging from a year and half (18 months) to 2 years (24 months) with an average of a year and 9 months (21 months) was planned.

All cases were assessed clinically and radiographically, fulfilling the following criteria.

Clinical assessment

(1) Presence or absence of foot pain or discomfort.
(2) Correction of the foot deformity:
    (a) Position of the heel in respect to the calf as seen from behind.
    (b) Prominence of the talar head.
    (c) Absence of the skin problems (callus, ulcer, etc.).
(3) STJ mobility.

Figure 5



A B

Intraoperative C-arm imaging, (a) anteroposterior view and (b) lateral view, showing the corrected position of the talus.

Table 3 Grading system: score of the clinical and radiographic results

Clinical results	Score
Foot pain	
Absent	2
Mild, not over the talar head	1
Present, over the talar head	0
Foot deformity	
Full correction (< 10° valgus)	2
Partial correction (valgus < 15°)	1
Valgus > 15°	0
Subtalar joint mobility	
Preserved	2
Limited	1
Stiff (immobile)	0
Patient (or parent) satisfaction	
Satisfied	2
Accepting	1
Unsatisfied	0
Radiographic results	Score
Anterior talocalcaneal angle	
<30°	2
30–40°	1
>40°	0
Talonavicular angle	
<30°	2
30–40°	1
>40°	0
Talonavicular coverage angle	
<5° (i.e. >90% coverage)	2
5–10° (i.e. 75–90% coverage)	1
>10° (i.e.<75% coverage)	0
Anterior talo-first metatarsal angle	
<4°	2
4–10°	1
>10°	0
Lateral talocalcaneal angle	
<45°	2
45–50°	1
>50°	0
Lateral talo-first metatarsal angle	
<4°	2
4–10°	1
>10°	0

(4) Patient (or parents) satisfaction.

Radiographic assessment

Weight-bearing anteroposterior and lateral radiograph of the ankle and foot were taken, immediately postoperatively (the day after operation), after change of the cast and removal of K-wires (6 weeks), after cast removal (8 weeks), and at 2-month interval. The TCA_1 TNA, TNCA, the $TFMA_1$, the TCA_2, and the $TFMA_2$ were measured. The degree of correction of the angle measure was calculated by comparing the postoperative measures with those of the preoperative.

Intraobserver and interobserver variability

Intraobserver variability and interobserver variability were studied. Ten feet were examined and scored independently by four observers. On a separate occasion, two of the observers repeated the assessments of the same feet in the absence of information from the initial observations. The chance corrected and weighted kappa statistics for observer agreement, both for interobserver and intraobserver variability demonstrated satisfactory repeatability of the foot grading system. The overall intraobserver mean weighted kappa was χw=+0.61 (range SE χ=0.011–0.053) and the overall interobserver mean weighted kappa was χw=+0.54 (range SE χ=0.009–0.041).

Results

In the previous series or literatures, evaluation of hindfoot valgus was classified as stated by Stevens and Toomey [10] depending only on the radiographic measures and the relationship between the talus, tibia, and calcaneus. The evaluation in that scheme was lacking the clinical objective and subjective results.

Therefore, a grading system was suggested in this study depending on both clinical and radiographic measures and correlating them with point scores (Table 3).

The clinical evaluation (eight points) was based on the following criteria:

(1) Presence or absence of foot pain (two points).
(2) Correction of the foot deformity (two points).
(3) STJ mobility (two points).
(4) Patient (or parents) satisfaction (two points).

The radiographic evaluation (12 points) relied on the following anteroposterior and lateral weight-bearing angle measures:

(1) TCA_1 measure (two points).
(2) TNA measure (two points).
(3) TNCA measure, that is, talar head coverage (two points).
(4) $TFMA_1$ measure (two points).
(5) TCA_2 measure (two points).
(6) $TFMA_2$ measure (two points).

Clinical evaluation

Foot pain

There was no foot pain postoperatively anywhere in the foot particularly over the talar head in seven patients (14 cases or feet) and in the right foot of one patient.

Table 4 Preoperative and postoperative angle measure

Preoperative measure							Postoperative measure					
Case number	TCA_1	TNA	TNCA	$TFMA_1$	TCA_2	$TFMA_2$	TCA_1	TNA	TNCA	$TFMA_1$	TCA_2	$TFMA_2$
1	63°	40°	30°	40°	53°	15°	20°	28°	2°	3°	40°	5°
2	54°	77°	62°	22°	49°	39°	36°	31°	5°	5°	30°	9°
3	70°	48°	62°	38°	77°	40°	34°	33°	5°	8°	32°	5°
4	65°	62°	70°	32°	50°	32°	26°	22°	3°	3°	33°	3°
5	72°	42°	23°	43°	50°	55°	30°	26°	1°	3°	20°	4°
6	65°	35°	28°	19°	53°	22°	35°	23°	5°	7°	43°	4°
7	48°	38°	38°	10°	48°	22°	37°	18°	7°	6°	33°	4°
8	53°	75°	63°	20°	47°	38°	35°	30°	5°	8°	30°	9°
9	76°	48°	62°	38°	77°	40°	34°	33°	5°	8°	32°	5°
10	50°	35°	20°	25°	52°	20°	22°	15°	0°	2°	26°	2°
11	65°	36°	30°	43°	58°	20°	30°	20°	2°	3°	38°	3°
12	50°	54°	53°	25°	68°	38°	35°	38°	6°	10°	43°	6°
13	50°	48°	45°	35°	63°	42°	42°	32°	9°	10°	38°	3°
14	68°	45°	41°	40°	50°	38°	33°	10°	0°	2°	34°	4°
15	60°	55°	35°	48°	67°	42°	28°	18°	0°	3°	25°	1°
16	48°	38°	29°	28°	48°	22°	23°	18°	0°	2°	25°	4°
17	54°	38°	20°	30°	48°	28°	22°	20°	1°	2°	31°	1°
18	55°	45°	37°	40°	50°	28°	33°	31°	6°	9°	49°	17°
19	65°	35°	28°	28°	55°	22°	35°	30°	6°	9°	43°	8°
20	77°	50°	24°	26°	48°	23°	36°	20°	3°	6°	25°	8°

TCA_1, anterior talocalcaneal angle; TCA_2, lateral talocalcaneal angle; $TFMA_1$, anterior talo-first metatarsal angle; $TFMA_2$, lateral talo-first metatarsal angle; TNA, talonavicular angle; TNCA, talonavicular coverage angle.

Table 5 Preoperative and postoperative average angle measure

Angle	Average measure±SD	
	Preoperative	Postoperative
TCA_1	60.4±12.2°	31.3±8.6°
TNA	47.2±8.4°	24.8±4.1°
TNCA	40±6.7°	3.6±1.2°
$TFMA_1$	31.5±5.9°	5.5±0.9°
TCA_2	55.5±9.6°	33.5±6.3°
$TFMA_2$	31.3±6.5°	5.25±1.1°

TCA_1, anterior talocalcaneal angle; TCA_2, lateral talocalcaneal angle; $TFMA_1$, anterior talo-first metatarsal angle; $TFMA_2$, lateral talo-first metatarsal angle; TNA, talonavicular angle; TNCA, talonavicular coverage angle.

There was only mild foot discomfort postoperatively but not over the talar head and no frank pain in two patient (four cases or feet) and in the left foot of one patient. This is in contrast to frank foot pain particularly over the bony prominence (talar head) preoperatively (in eight cases) or discomfort (in 12 cases). Pain disappeared in the postoperative gait training and physiotherapy period. Other nonmechanical pain as that at the site of sutures or K-wires was of no significance as it was short termed and disappeared spontaneously.

Foot deformity

The degree of hindfoot valgus improved postoperatively in all of the 11 patients (20 cases or feet). However, only one patient (two cases or feet) had residual hindfoot valgus less than 15° at the last follow-up which was attributed to under-correction of the hindfoot valgus owing to severe preoperative tight Achilles' tendon, which was difficult to achieve full correction without calcaneal subluxation in such two cases. This is in contrast to two patients (four feet) who had severe (20° or more) hindfoot valgus deformity, and nine patients (16 feet) had moderate (15–<20°) deformity preoperatively.

All cases had no problem with the footwear. No cases recorded a discomfort or a skin problem as the prominent talar head was sufficiently corrected. All wore ordinary shoes.

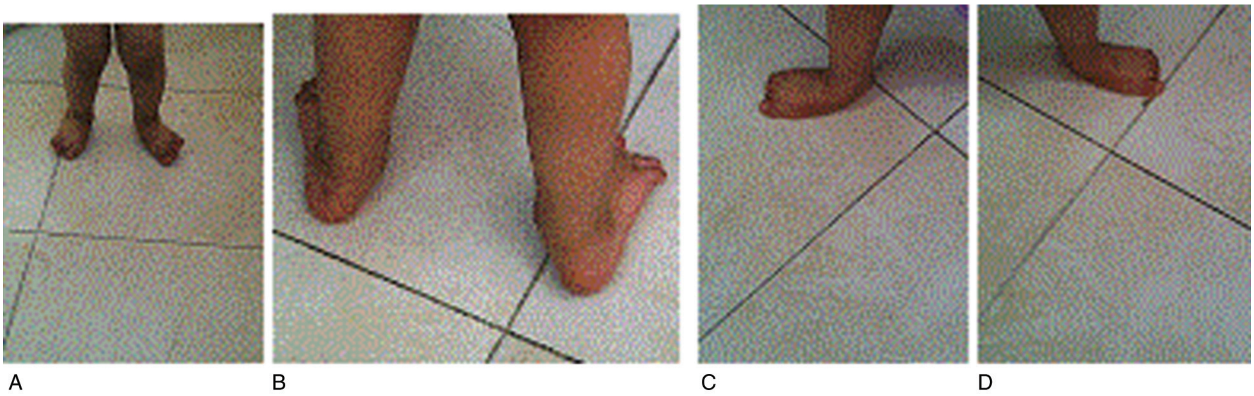
Subtalar joint mobility

Following the postoperative physiotherapy period, five patients (10 cases or feet) and the right foot of one patient had supple (mobile) STJ with passive and active movements, whereas four patients (eight cases or feet) and the left foot of one patient had some limitation of full inversion rather than eversion, probably owing to some osseous changes in the talocalcaneal complex.

Patient (or parents) satisfaction

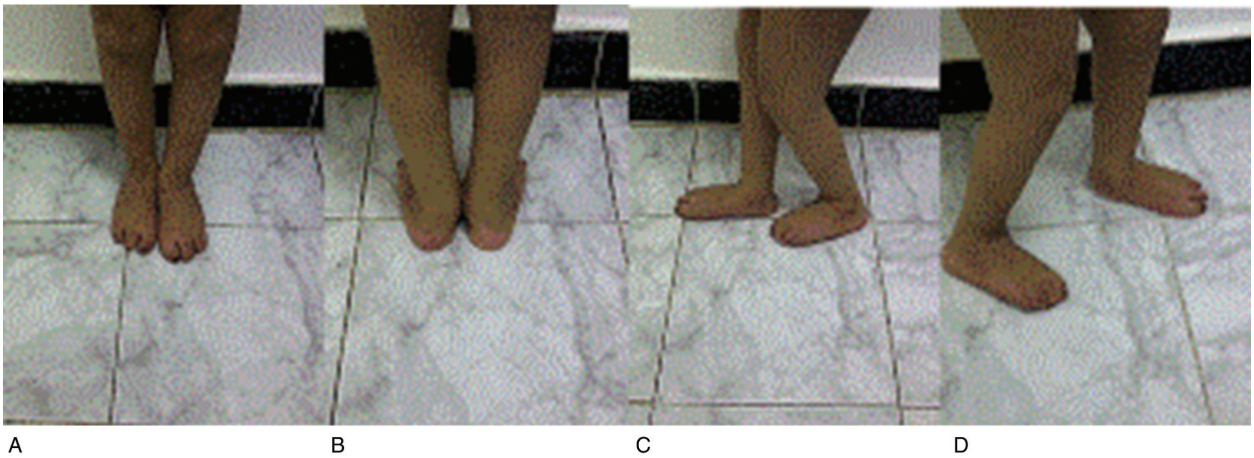
Eight patients (15 cases or feet) were fully satisfied, whereas three patients (five cases or feet) were not fully satisfied but also not dissatisfied and were accepting the result owing to the disappearance of preoperative pain/discomfort, the correction of the foot deformity, the

Figure 6



Preoperative: (a) bilateral hind-feet valgus as shown from the front with prominent talar heads, (b) from behind with outward deviation of heel-cords, and from the inner sides with depressed medial longitudinal arches of the (c) right and left foot.

Figure 7



One-year postoperative: full correction of both sides with no residual valgus as shown from (a) the front, from behind with (b) central heel cord, and from the inner side of the (c) right side and (d) left side.

better footwear, and the overall improvement of the gait.

Radiographic evaluation

In all of the 11 patients (20 cases or feet), there was improvement (decrease) in all angle measures postoperatively as compared with the preoperative ones, but with variable degrees (Table 4).

Anterior talocalcaneal angle

Preoperative measure ranged from 48 to 77°, with an average of 60.4°, whereas the postoperative measure ranged from 20 to 42°, with an average of 31.3°.

Talonavicular angle

Preoperative measure ranged from 35 to 77°, with an average of 47.2°, whereas postoperative measure ranged from 15 to 38°, with an average of 24.8°.

Talonavicular coverage angle

Preoperative measure ranged from 20 to 70°, with an average of 40°, whereas postoperative measure ranged from 0 to 9°, with an average of 3.6°.

Anterior talo-first metatarsal angle

Preoperative measure ranged from 10 to 48°, with an average of 31.5°, whereas postoperative measure ranged from 2 to 10° with an average of 5.5°.

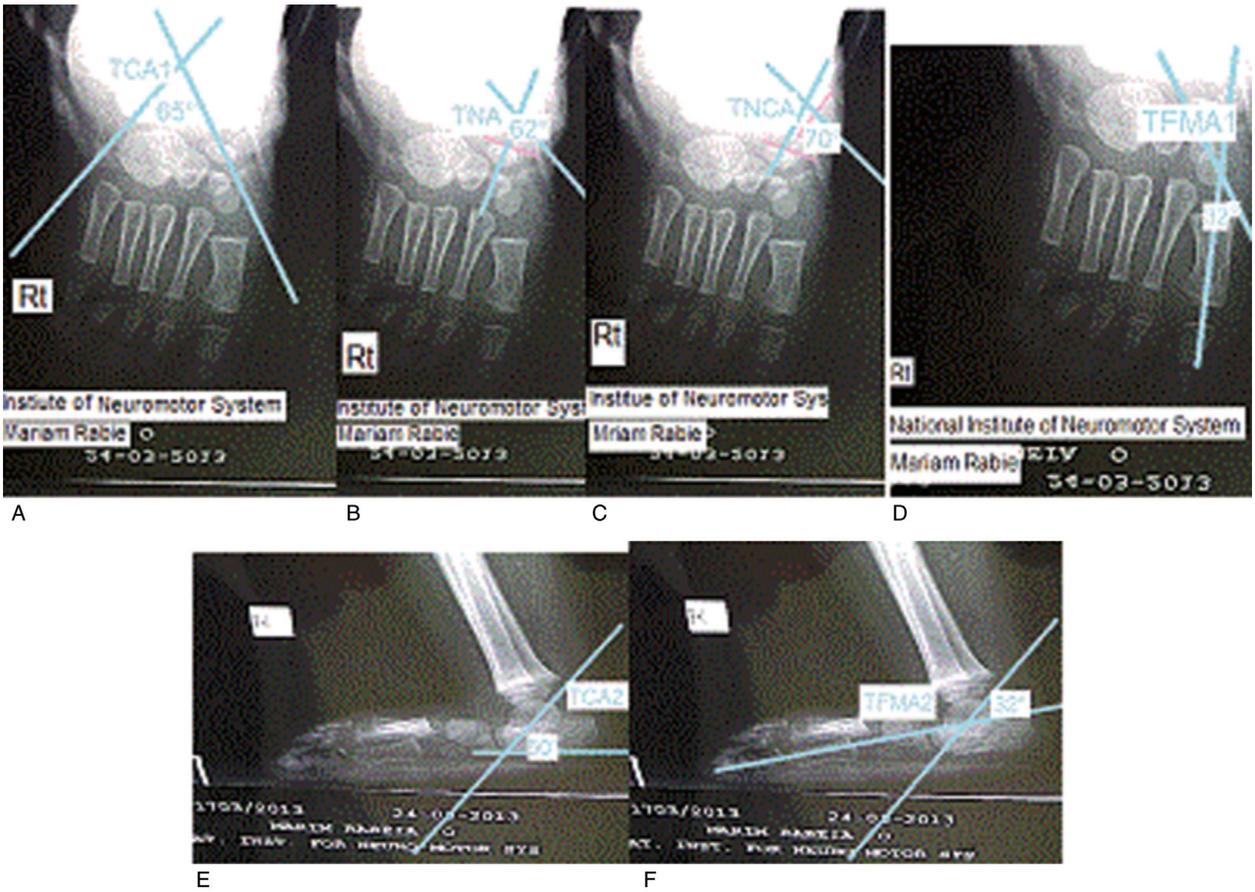
Lateral talocalcaneal angle

Preoperative measure ranged from 47 to 77° with an average of 55.5°, whereas postoperative measure ranged from 20 to 49° with an average of 33.5°.

Lateral talo-first metatarsal angle

Preoperative measure ranged from 15 to 55°, with an average of 31.3°, whereas postoperative measure ranged from 1 to 17°, with an average of 5.25°.

Figure 8



Preoperative radiography: anteroposterior view of the right foot showing talar head medial subluxation out of the navicular socket with angle measure of (a) TCA_1 65°, (b) TNA 62°, (c) TNCA 70°, and (d) $TFMA_1$ 32° and lateral views of the right foot showing plantar flexion of the talus on the calcaneus with angle measure (e) TCA_2 of 50° and (f) $TFMA_2$ of 32°. TCA_1, anterior talocalcaneal angle; TCA_2, lateral talocalcaneal angle; $TFMA_1$, anterior talo-first metatarsal angle; TNA, talonavicular angle; TNCA, talonavicular coverage angle.

Table 5 shows the average preoperative and postoperative all angles measures with calculation of the SD through its mathematical equation.

No major complication occurred. Only superficial wound infection occurred in one case (no. 9). It was treated by local wound debridement and antibiotic administration. The infection was eradicated within 2 weeks and followed up for 24 months without recurrence. No case of deep infection was recorded.

Clinical and radiographic assessments were achieved over the follow-up period (Figs 6–11).

The results were graded into four categories as excellent, good, fair, and poor according to the total calculated score. If the total score was 18–20, the result would be considered excellent, 15–17 would be good, 12–14 would be fair, and less than 12 would be poor.

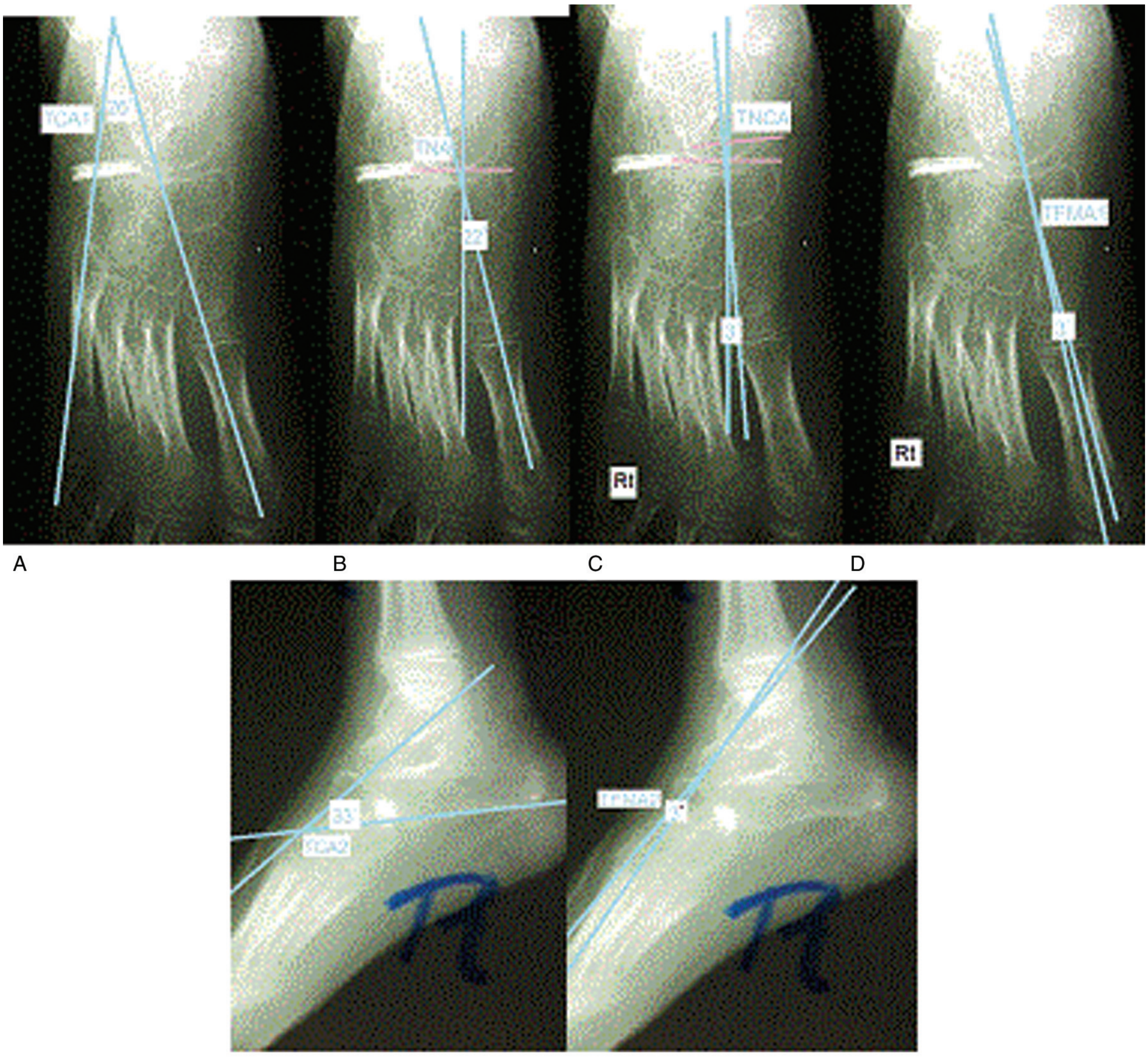
According to this grading system, there were eight excellent results, eight good results, four fair results, and no poor results (Table 6).

Discussion

CP is a permanent nonprogressive brain damage that mainly affects the cognitive and motor functions owing to perinatal brain insult. The spastic type of CP accounts for 85% of the affected patients and results in muscle imbalance, joint deformity, torsional malalignment, bony changes in growing children, and disturbed gait pattern in ambulatory patients [11].

Hindfoot valgus deformity is common in spastic CP, especially in diplegia [12]. Because of the spasticity and muscular contractures, alterations develop in the anatomic relation between the tarsal bones. These changes include external rotation of the calcaneus, and internal rotation and inferior subluxation of the talus. Additional structural alterations develop because of the abnormal forces applied through the midfoot and forefoot and loss of stability, which result in midfoot break [13]. Foot pain accompanies the foot deformity and results from midfoot break with prominent talar head in the weight-bearing part of the foot [11,13]. Radiographically, there is increase in

Figure 9



Postoperative radiography (after a year): anteroposterior view right foot showing talar head containment in the navicular socket with angle measure of (a) TCA_1 26°, (b) TNA 22°, (c) TNCA 3°, and (d) $TFMA_1$ 3° and lateral views of right foot showing dorsiflexion of the talus on the calcaneus with angle measure (e) TCA_2 of 33° and (f) $TFMA_2$ of 3°. TCA_1, anterior talocalcaneal angle; TCA_2, lateral talocalcaneal angle; $TFMA_1$, anterior talo-first metatarsal angle; TNA, talonavicular angle; TNCA, talonavicular coverage angle.

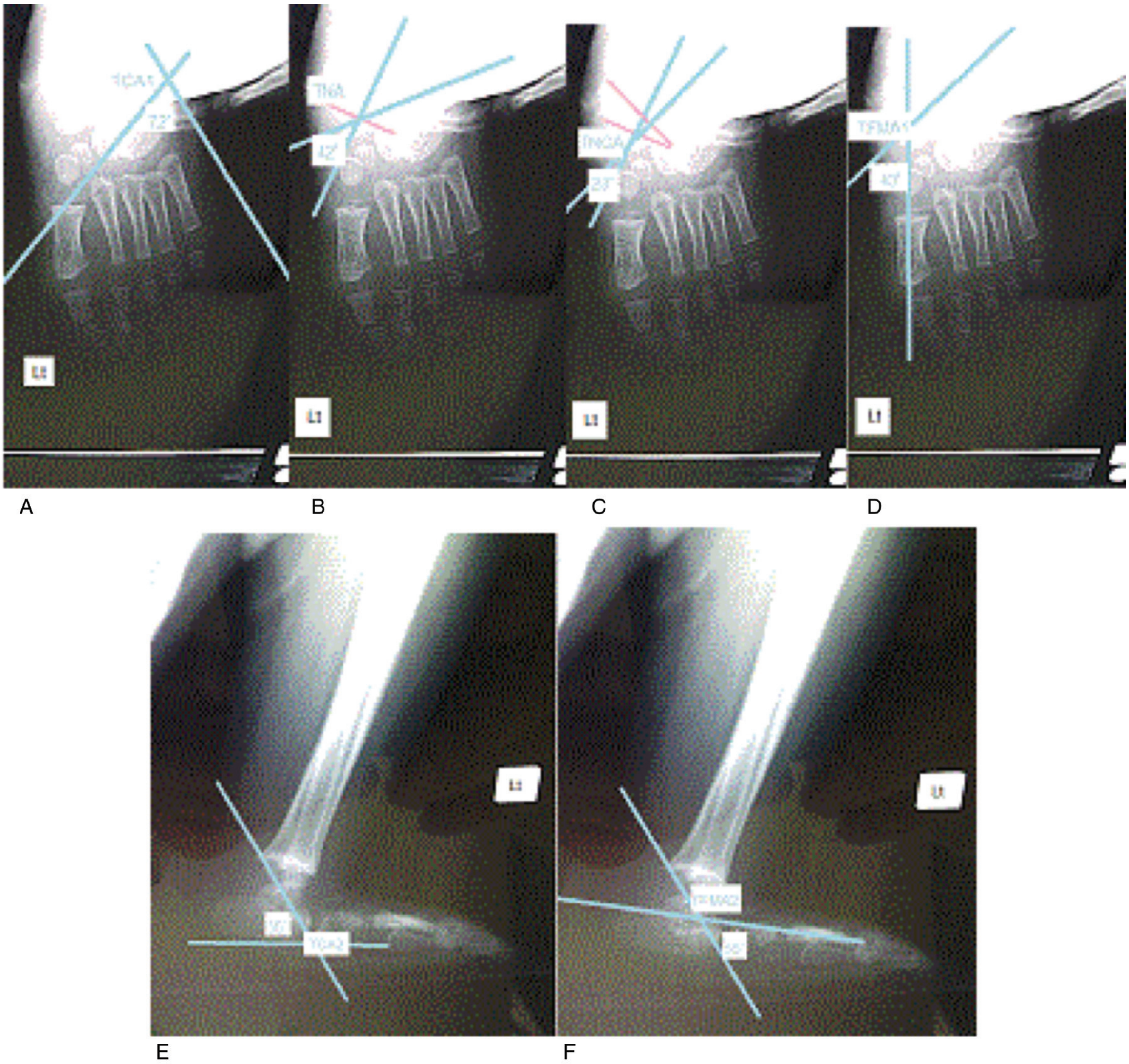
the anterior talocalcaneal Kite's angle, TNA, TNCA, $TFMA_1$, lateral TCA, and lateral talo-first metatarsal Meary's angle [14–18]. A short stride length and low velocity are also observed owing to spasticity, which also causes a reduced step length. With progression of the deformity, other pathologic features develop, including forefoot supination and hallux valgus [19].

Surgery is the definitive measure, which is indicated in moderate to severe hindfoot valgus deformity causing mechanical instability affecting the child's gait and in children not tolerating the ankle-foot orthoses or not responding to prolonged nonoperative course (at least 6 months) with persistent pain, deformity, callus, or skin ulceration [20]. Surgical interventions improve the gait as examined by gait analysis [21]. Multilevel surgeries, soft tissue and bony procedures, if well selected have significant improvement in ankle and foot functions as well as the spastic muscle function [22]. Numerous operative procedures have been described in the last decades to correct hindfoot valgus deformities.

There are four levels of surgical correction of hindfoot valgus deformity: (a) soft-tissue procedures alone; (b) osteotomies, (c) pseudarthrosis or arthroereisis without arthrodesis; and (d) arthrodesis, either limited, or triple arthrodesis.

The simplest soft-tissue procedures include ATL and/or peroneal tendon lengthening [23]. In general, soft-tissue procedures alone cannot withstand the forces of weight bearing, and the deformity tends to recur [24].

Figure 10

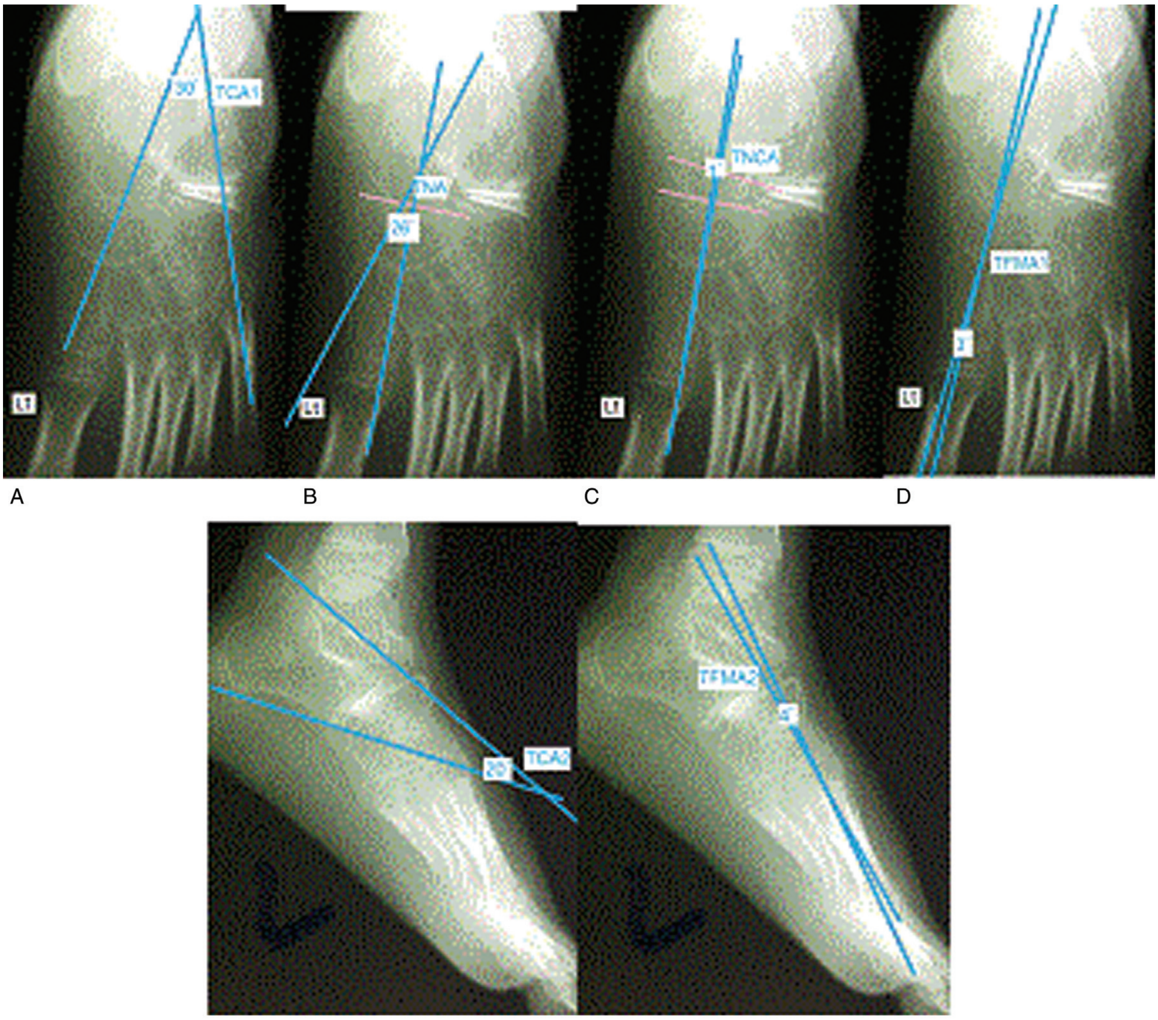


Preoperative radiography: anteroposterior view of the left foot showing talar head medial subluxation out of the navicular socket with angle measure of (a) TCA_1 of 72°, (b) TNA of 42°, (c) TNCA of 23°, and (d) $TFMA_1$ of 43°, and lateral views of the left foot showing plantar flexion of the talus on the calcaneus with angle measure (e) TCA_2 of 50° and (f) $TFMA_2$ of 55°. TCA_1, anterior talocalcaneal angle; TCA_2, lateral talocalcaneal angle; $TFMA_1$, anterior talo-first metatarsal angle; TNA, talonavicular angle; TNCA, talonavicular coverage angle.

They only convert painful deformity to a painless one, owing to the fact that pes valgus deformity and the depressed medial longitudinal arch had both muscular as well as bony contributions. Most surgeons combine soft-tissue procedures with concurrent bony procedures to change the shape of the foot [24,25].

The second level of surgical intervention for hindfoot valgus includes osteotomies. Most of the reports of various osteotomies to correct hindfoot valgus deformity were relatively small series with short follow-up. The Dwyer [26] lateral opening-wedge osteotomy of the posterior calcaneus to correct hindfoot valgus was located at the STJ injuring it, and was not located at the angle or center of rotational angulation of the deformity. Evan [27] recommended elongation of the lateral column as a treatment for planovalgus or calcaneovalgus foot, but stated at that time that the operation was inappropriate for children with spastic paresis because of high prevalence of overcorrection, or in other paralytic children because of osteopenia and muscle imbalance deteriorating the results. Philips [28] reported 20-year follow-up on 23 of the feet originally operated for calcaneal lengthening osteotomy by Evan [27] as good or very good results in 17 feet but did not define the criteria for classifying results. There were also noted degenerative changes in the calcaneocuboid joint in all 15 of the patients with good results. More recently, Mosca [1], Andreacchio *et al.* [2], and Hanna *et al.* [3], modified the procedure described by Evan and reported the ability of the lateral foot column lengthening to correct the abnormal anatomy of the deformity while preserving the STJ motion. Mosca

Figure 11



Postoperative radiography (after a year): anteroposterior view of the left foot showing talar head containment in the navicular socket with angle measure of (a) TCA_1 of 30°, (b) TNA of 26°, (c) TNCA of 1°, and (d) $TFMA_1$ of 3°, and lateral views of the left foot showing dorsiflexion of the talus on the calcaneus with angle measure of (e) TCA_2 of 20° and (f) $TFMA_2$ of 4°. TCA_1, anterior talocalcaneal angle; TCA_2, lateral talocalcaneal angle; $TFMA_1$, anterior talo-first metatarsal angle; TNA, talonavicular angle; TNCA, talonavicular coverage angle.

Table 6 Categories and number of cases

Category	Total score	Number of cases
Excellent	18–20	8
Good	15–17	8
Fair	12–14	4
Poor	<12	0

[1] reported at an average of 2–3 years of follow-up, satisfactory results in 29 of 31 feet, and failure in the two feet with the most severe deformity. Eight had the addition of either cuneiform wedge osteotomy or talocalcaneal arthrodesis. Andreacchio *et al.* [2] reported at an average of 4.1 years of follow-up, 17 feet had good, two fair, and four poor outcomes which resulted from recurrence of deformity. Hanna *et al.* [3] reported at an average of 2 years of follow-up, five feet had excellent, 17 good, five fair, and no poor results. Previous studies showed that calcaneal lengthening osteotomy was suitable for mild to moderate, flexible hindfoot valgus deformity [2,29]. In contrast, some studies recommended calcaneal lengthening, even for severe hindfoot valgus deformity [1]. Because of the anatomic variation of the anterior and middle articular facets of the calcaneus, the calcaneal lengthening osteotomy can be intra-articular causing articular damage to the STJ [30]. Torosian and Dias [31] described a displacement osteotomy of the os calcis only to correct hindfoot valgus in myelomeningocele with STJ preservation. The procedure succeeded to correct the valgus in 31 out of 38 feet over a follow-up period more than 5 years, but failed to correct forefoot abduction or medial longitudinal arch collapse [32]. Rathjen and Mubarak [9] described a combination of a sliding calcaneal osteotomy, an opening-wedge cuboid osteotomy, and a pronation, plantar flexion closing-wedge osteotomy of the medial cuneiform in addition

to appropriate soft-tissue releases and compared favorably with similar series in achieving excellent foot alignment parallel to the axis of progression in 23 out of 24 feet over a follow-up period of an average of 1½ years. However, there was violation of the STJ articular surface owing to anatomic variation of the calcaneal facets [30].

In the current study, the calcaneus was preserved of osteotomy. Through a double-column foot osteotomy, the medial foot column was shortened by a plantarward-based medial cuneiform closing wedge, whereas the lateral foot column was lengthened by a laterally based cuboid opening wedge filled by wedge resected from the medial cuneiform. The procedure was applied to moderate and severe mobile (flexible) hindfoot valgus and reported 20 feet over a follow-up period of an average of $1\frac{3}{4}$ years; eight had excellent, eight good, four fair, and no poor results, according to a preset scoring system combining both clinical and radiographic results. It was not only a redirectional osteotomy of the acetabulum pedis that corrects subluxation or dislocation of the STJ, but also strengths the windlass mechanism by tightening the plantar fascia restoring the medial longitudinal arch height [33]. It had the advantage of lateral column foot lengthening, the medial column foot shortening, and the preservation of the STJ mobility.

This study arrived at the fact that paralytic subtalar hindfoot valgus is presented with certain pattern of muscle paresis, depending on foot evertors/invertors power. There were two patterns of muscle paresis, namely, without or with evertors/invertors imbalance. Though the two groups differ in pathogenesis, there is not much difference in the outcome. The first group with no evertors/invertors imbalance is mostly owing to developmental changes in the foot, such as bowstringing of the calcaneus predisposing to talonavicular subluxation, and ligamentous laxity depressing the medial longitudinal arch. The second group with evertors/invertors imbalance is mostly owing to adaptive changes caused by forces on the foot with powerful peronei relative to tibialis anterior and posterior muscles, and also, powerful long toes extensors, driving the talonavicular joint to subluxate laterally. In the two patterns, the other components of the deformity are exactly the same. Cases with muscle imbalance require, in addition to double-column foot osteotomy, peroneal tendon lengthening. Moreover, cases with powerful triceps surae require ATL provided that there is no strong dorsiflexors.

The third level of surgical intervention is peudarthrosis or arthroereisis of the STJ to restrict eversion either by placing a bone block in the sinus tarsi or by a synthetic implant was followed by implant problems [34]. Da Silva *et al.* [35] used a cancellous screw and a silastic or polypropylene dome of high molecular weight. It is a noncomparable modality to the current study.

The fourth or final level of surgical intervention is a salvage procedure of either limited fusion or multiple joint fusion of the STJ complex. Limited or extra-articular arthrodesis of the STJ initially described by Grice [4] had the benefit of preserving the subtalar articular joint cartilage with minor interference with bone growth, but was followed by recurrence of the foot deformity owing to graft resorption or failure. It was mainly provided to patients with poor ambulation. Triple arthrodesis represents the final and most definitive surgical option for valgus foot deformity. It is reliable in correcting deformity and maintaining normal foot position. Unfortunately, it also increases the stresses at adjacent joints and limits the growth of the foot in children [36].

Conclusion

The double-column foot osteotomy shortening the medial foot column by medial cuneiform closing wedge and lengthening the lateral foot column by cuboid opening-wedge osteotomy to correct moderate to severe hindfoot valgus in ambulatory children with spastic CP compared favorably with similar series that used other techniques and offered option for achieving foot alignment, improving pain and skin problems, and avoiding the problems associated with arthrodesis.[36].

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Conflicts of interest

There are no conflicts of interest.

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