

Long-term Results of Comprehensive Clubfoot Release Versus the Ponseti Method: Which Is Better?

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Abstract

Background Clubfoot can be treated nonoperatively, most commonly using a Ponseti approach, or surgically, most often with a comprehensive clubfoot release. Little is known about how these approaches compare with one another at longer term, or how patients treated with these approaches differ in terms of foot function, foot biomechanics, or quality-of-life from individuals who did not have clubfoot as a child.

Questions/purposes We compared (1) focused physical and radiographic examinations, (2) gait analysis, and

(3) quality-of-life measures at long-term followup between groups of adult patients with clubfoot treated either with the Ponseti method of nonsurgical management or a comprehensive surgical release through a Cincinnati incision, and compared these two groups with a control group without clubfoot.

Methods This was a case control study of individuals treated for clubfoot at two separate institutions with different methods of treatment between 1983 to 1987. One hospital used only the Ponseti method and the other mainly used a comprehensive clubfoot release. There were 42 adults (24 treated surgically, 18 treated with Ponseti method) with isolated clubfoot along with 48 healthy control subjects who agreed to participate in a detailed analysis of physical function, foot biomechanics, and quality-of-life metrics.

Results Both treatment groups had diminished strength and motion compared with the control subjects on physical examination measures; however, the Ponseti group had significantly greater ankle plantar flexion ROM ($p < 0.001$), greater ankle plantar flexor ($p = 0.031$) and evorator ($p = 0.012$) strength, and a decreased incidence of osteoarthritis in the ankle and foot compared with the surgical group. During gait the surgical group had reduced peak ankle plantar flexion ($p = 0.002$), and reduced sagittal plane hindfoot ($p = 0.009$) and forefoot ($p = 0.008$) ROM during the preswing phase compared with the Ponseti group. The surgical group had the lowest overall ankle power generation during push off compared with the control subjects ($p = 0.002$). Outcome tools revealed elevated pain levels in the surgical group compared with the Ponseti group ($p = 0.008$) and lower scores for physical function and quality-of-life for both clubfoot groups compared with age-range matched control subjects ($p = 0.01$).

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Conclusions Although individuals in each treatment group experienced pain, weakness, and reduced ROM, they were highly functional into early adulthood. As adults the Ponseti group fared better than the surgically treated group because of advantages including increased ROM observed at the physical examination and during gait, greater strength, and less arthritis. This study supports efforts to correct clubfoot with Ponseti casting and minimizing surgery to the joints, and highlights the need to improve methods that promote ROM and strength which are important for adult function.

Level of Evidence Level III, prognostic study.

Introduction

Clubfoot is a congenital foot deformity occurring in as many as three per 1000 births [38]. The Ponseti method is the most common treatment option for clubfoot [25]. This technique includes serial manipulation of the newborn's foot, casting, heel cord tenotomy, and bracing. Before the Ponseti method, the comprehensive clubfoot surgical release was the standard of care and still is used for individuals when nonoperative management fails. Beginning in 1983, a Cincinnati incision was used to perform the comprehensive release and obtain correction of the foot deformity in all three planes [6, 33].

Although some studies have reported on pain and function in patients treated with the Ponseti method [1, 5, 13, 22, 28] and others have reported on the comprehensive surgical release [1, 5, 8, 9, 11, 12, 17, 23, 26, 29, 31, 32, 35, 37], to our knowledge no study has compared these approaches using focused functional and biomechanical analyses, and none has compared quality-of-life measures for patients who had these approaches with those of individuals with normal feet. Such comparisons are important, as the patients treated with these two methods during the 1980s and 1990s are now young adults in the workforce. It would be important to identify their level of function and any impairments.

The purpose of our study was to compare (1) focused physical and radiographic examinations, (2) gait analysis, and (3) quality-of-life measures at long-term followup between two groups of patients with clubfoot treated with different techniques and to compare these two groups with a control group without clubfoot.

Patients and Methods

This was a case control study comparing the long-term results of physical and radiographic examinations, gait, and quality-of-life measures among three groups: healthy control subjects, individuals surgically treated for clubfoot and

individuals treated for clubfoot using the Ponseti method. The study took place in a motion analysis laboratory at a specialized pediatric orthopaedic hospital. Recruitment was conducted at three independent institutions during a 3-year period. Forty-eight healthy control subjects were recruited from Marquette University, and 24 individuals surgically treated and 18 nonsurgically treated using the Ponseti method were recruited from University of Iowa Hospitals and Clinics. Patients were included if they had a diagnosis of isolated clubfoot and treatment at one of the participating institutions. Patients with teratologic clubfeet, arthrogryposis, and neurologic abnormalities or syndromes (eg, constriction bands) were excluded. All participants signed the institutional review board-approved consent form.

On-site medical records reviews showed 242 patients who had clubfoot surgery between 1983 and 1987 at the Shriners Hospitals for Children – Chicago, and of these, 179 met the inclusion criteria, 102 were contacted, and 24 agreed to participate (surgical group, 17 men, seven women; mean \pm SD age, 21.8 \pm 2.3 years; 37 clubfeet total, 11 unilateral, 13 bilateral). Although the patients were not graded as infants all had severe enough clubfeet to be referred to a treating physician. Those who had comprehensive releases all had manipulation and casting treatment fail either at this institution or elsewhere. The treatment protocol was to place a long leg cast and repeat weekly as long as the deformity was improving. However, the Ponseti method was not used, and if the deformity was not responding after several casts or the patient was 6 months old, a comprehensive clubfoot release was performed with a Cincinnati incision before the patient was 18 months old [35]. Of the 24 patients (37 feet) treated with comprehensive release, all surgeries were performed by the same surgeon (KNK), and 12 patients had additional surgery for residual deformity at a mean age of 6.9 years (range, 2–16 years) (Fig. 1).

On-site medical record reviews identified 82 patients who underwent Ponseti treatment from 1983 to 1987 at a participating institution, of which 56 were contacted and 18 agreed to participate (Ponseti group, nine men, nine women; mean age, 29.2 \pm 5.6 years; 29 clubfeet total, seven unilateral, 11 bilateral). The patients in this group underwent the Ponseti treatment at a mean of 12.4 days after birth (range, 1–90 days), and were treated with casting for a mean of 10 months using the same technique [22]. Of the 18 patients (29 feet), 12 patients (16 feet) required additional surgery at an average age of 3.3 years. None of these patients received a comprehensive clubfoot release but rather had isolated corrective procedures (Fig. 1).

Both groups were compared with 48 healthy young adults (control group, 29 men, 19 women; mean age, 23.2 \pm 2.4 years) recruited from a third collaborating institution. Examination of the demographic data showed

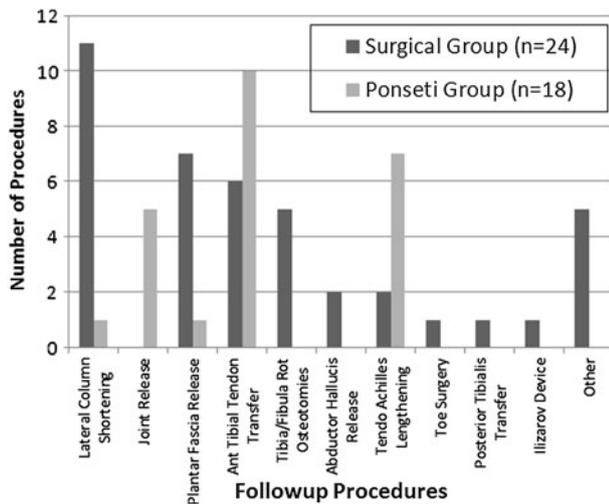


Fig. 1 The followup surgical procedures performed on both treatment groups are shown. Ant = anterior; Rot = rotation.

negligible differences in height and weight among the groups; however, there was an age difference. The mean age of study subjects at the time of this evaluation was younger in the surgical group than in the Ponseti group by 7.4 years (21.8 ± 2.3 years versus 29.2 ± 5.6 years, $p < 0.001$) and in the control group by 1.4 years (23.2 ± 2.4 versus 21.8 ± 2.3 years, $p = 0.02$). The mean age of subjects in the Ponseti group was older than that in the control group (29.2 ± 5.6 versus 23.2 ± 2.4 years, $p < 0.001$). The gender ratio of the participants to that of the entire treated population from both institutions was similar.

Physical Examination

In accordance with the International Clubfoot Study Group rating score, a physical therapist measured goniometric ROM of the ankles and feet while the participant was in the prone position [4]. Anthropometric data including calf circumference, leg length, and foot length also were recorded.

Radiographic Assessment

Two orthopaedic surgeons graded osteoarthritic changes (1 = none, 2 = doubtful, 3 = minimal severity, 4 = moderate, 5 = severe) using standing foot radiographs according to criteria established by Kellgren and Lawrence [19] and used by Dobbs et al. [11]. The surgeons were blinded to the treatment groups. Results were reported as frequency, or percentage, of joints with moderate to severe osteoarthritis.

Strength Evaluation

Two ankle strength assessments were performed: (1) plantar flexor strength was measured using a single-leg heel rise test [14, 24], and (2) plantar flexor, dorsiflexor, and inversion and eversion peak isokinetic torque were measured using the Biodex System III[®] (Biodex Medical Systems, Inc, Shirley, NY, USA) with values normalized to body weight.

Gait Analysis

Participants underwent quantitative gait analysis using a Vicon[®] 14 MX[™] camera three-dimensional motion analysis system (Vicon Motion Systems Ltd, Oxford, UK) and two force-plates (AMTI, Newton, MA, USA). The Milwaukee foot model was used to measure segmental foot and ankle motion, which incorporates radiographic referencing [20]. Gait data and temporal spatial parameters were averaged over three trials for each participant. Gait kinematic and kinetic minimum and maximum (peaks), mean, and ROM were summarized for each phase of the gait cycle as described by Perry and Burnfield (initial contact, loading response, midstance terminal stance, preswing, initial swing, midswing, and terminal swing) [30].

Outcomes Assessment

Measures of pain, satisfaction, function, and activity level were made using the American Orthopaedic Foot and Ankle Society (AOFAS) ankle-hindfoot and midfoot scales [21], the International Clubfoot Study Group scores [4, 36], and the SF-36 [27]. The SF-36 scores were normalized with values of 50 ± 10 representing the mean of the general population.

Statistical Analysis

We used SAS[®] Version 9.1 (SAS Institute, Inc, Cary, NC, USA) for all statistical analyses. In participants with bilateral clubfeet, the right and left sides were averaged together because no statistical difference was determined between sides. Uninvolved feet were excluded. A Kruskal-Wallis (Wilcoxon) test was used to compare scores from the SF-36, AOFAS, and heel rise test owing to nonparametric results. Mann-Whitney 95% CIs were given for the median difference between groups. Regression analysis

Table 1. Physical examination ROM measures

Ankle and hindfoot ROM	Surgical group	Ponseti group	Control group
Plantar flexion (°)	25 (p < 0.001)*, (p < 0.001)†	41 (p < 0.001)†	42
Dorsiflexion (°)	5 (p < 0.001)*	3 (p < 0.001)*	20
Inversion (°)	21 (p < 0.001)*	26 (p = 0.03)*	31
Eversion (°)	5 (p < 0.001)*	5 (p < 0.001)*	28

* Significantly different from control group; † significant difference between Ponseti and surgical groups.

Table 2. Number of feet with moderate to severe osteoarthritis*

Joint	Number of feet		
	Surgical group (n = 37 feet)	Ponseti group (n = 29 feet)	Control group (n = 20 feet)
Subtalar	2 (6%)	2 (7%)	0
Talonavicular	2 (6%)	1 (3%)	0
Calcaneocuboid	2 (6%)	1 (3%)	0
Naviculocuneiform	1 (3%)	1 (3%)	0
Tibiotalar	4 (11%)	1 (3%)	0
First			

* Kellgren-Lawrence grading system [19] used.

Table 3. Strength evaluations (heel rise test and dynamometry)

Strength parameter	Surgical group	Ponseti group	Control group	p value surgical versus control group	p value Ponseti versus control group	p value surgical versus Ponseti group
Heel rise test (points)	3.5*†	4.7*†	5	< 0.0001	< 0.0001	0.0008
Plantar flexion (Nm/kg)	44*†	59*†	92	< 0.0001	< 0.0001	0.0311
Dorsiflexion (Nm/kg)	37*	39	43	0.0324	0.1588	0.0689
Inversion (Nm/kg)	15*	18*	26	< 0.0001	0.0004	0.1435
Eversion (Nm/kg)	15*†	21*†	24	< 0.0001	0.1030	0.0123

* Significantly different from control group; † significant difference between Ponseti and surgical groups.

Table 4. Temporal and spatial gait parameters

Temporal/spatial parameter	Surgical group	Ponseti group	Control group	p value surgical control group	p value Ponseti versus control group	p value surgical versus Ponseti group
Walking speed (m/second)	1.01*	1.10	1.18	< 0.0001	0.2267	0.2319
Cadence (steps/minute)	106.1	108.6	110.5	0.1021	0.5651	0.5576
Stride length (m)	1.13*	1.22	1.28	< 0.0001	0.2587	0.1762
Foot off (% gait cycle)	60.7	62.1	60.5	0.8989	0.2319	0.5576
Single support (% gait cycle)	42	42	43	0.1021	0.5049	0.8072
Double support (% gait cycle)	30*	26	24	< 0.0001	0.5049	0.1932

* Significantly different from control group (p < 0.0024).

controlled for age, BMI, and sex in the clinical strength and ROM results. The Benjamini-Hochberg method [3] was used for a 5% false discovery rate on all group comparisons for kinematic and kinetic data.

Results

Physical and Radiographic Examination Results

There were no differences in calf circumference, leg length, and foot length measurements between treatment groups. Both treatment groups showed reduced dorsiflexion, inversion, and eversion compared with the control subjects. The surgical group showed reduced passive plantar flexion compared with subjects from the Ponseti and control groups (Table 1). In the radiographic assessment, moderate to severe osteoarthritis was seen in 11 of 259 (4%) joints examined in the surgical group and six of 231 (3%) joints examined in the Ponseti group (Table 2). Strength evaluation showed plantar flexor weakness in subjects in the surgical and Ponseti groups compared with the control group, with subjects in the surgical group being the weakest. Ankle inversion also was notably weaker in subjects in the Ponseti and surgical groups compared with the control group, and subjects in the surgical group were weaker in eversion than subjects in the other groups (Table 3).

Gait Analysis

No differences were observed between the treatment groups for temporal or spatial parameters; however, subjects in the surgical group had reduced speed, stride length, and increased double support compared with subjects in the control group (Table 4). In all the kinematic and kinetic metrics where differences were measured, subjects in the Ponseti group more closely resembled subjects in the control group. Subjects in the Ponseti group had greater peak plantar flexion during preswing than subjects in the surgical group ($p = 0.002$) (Fig. 2). Subjects in the Ponseti and surgical groups showed reduced dorsiflexion throughout swing phase ($p < 0.001$). Foot progression angles were comparable among the subjects with the exception of preswing phase, where subjects in the Ponseti and surgical groups remained more external than subjects in the control group ($p < 0.001$). Subjects in the surgical group showed persistent hip internal rotation throughout the gait cycle compared with the control subjects ($p < 0.001$). Segmental foot and ankle motion analysis revealed that subjects in the Ponseti and surgical groups had a plantar flexion shift in hindfoot kinematics and corresponding dorsiflexion shift in the forefoot kinematics throughout the gait cycle, with decreased hindfoot ROM from terminal stance to preswing. However, only subjects in the surgical group were significantly different ($p < 0.008$) from the control subjects (Fig. 3). Compared with the other groups, peak ankle power generation during preswing was lowest for subjects in the surgical group ($p = 0.002$ versus control subjects). Subjects in the Ponseti and surgical groups had increased hip power generation during initial swing ($p < 0.001$) (Fig. 4).

Outcomes Assessment

The AOFAS hindfoot and midfoot scores were lower for the surgical group owing to pain, activity limitations, alignment, and hindfoot motion restrictions (Table 5). All SF-36 scores for the Ponseti and surgical groups were within ± 10 of the general population norms; however, all four physical components for the surgical group and physical functioning and general health subscores for the Ponseti group were lower than those for the control group (Table 6). The bodily pain score was the only difference between the Ponseti and surgical groups. Based on the International Clubfoot Study Group scoring of outcomes, 80% of the feet in the Ponseti group scored either excellent or good and 20% scored fair or poor. Conversely, 60% of the feet in the surgical group scored excellent or good and 40% scored fair or poor (Table 7).

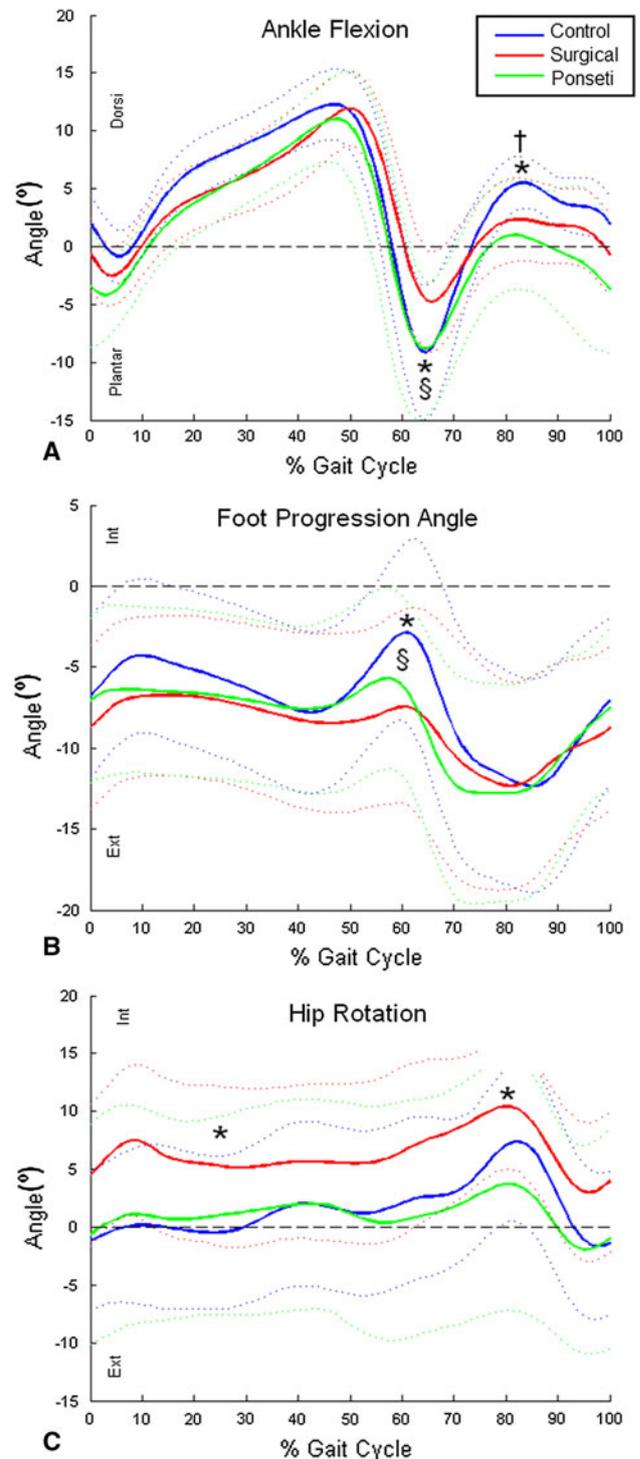


Fig. 2A–C (A) Ankle flexion, (B) foot progression angle, and (C) hip rotation are shown. *Significant difference between surgical and control groups ($p < 0.05$); †significant difference between Ponseti and control groups ($p < 0.05$); §significant difference between surgical and Ponseti groups ($p < 0.05$); solid lines = mean values; dotted lines = SD; Plantar = plantar flexion; Dorsi = dorsiflexion; Inv = inversion; Ev = eversion; Int = internal; Ext = external.

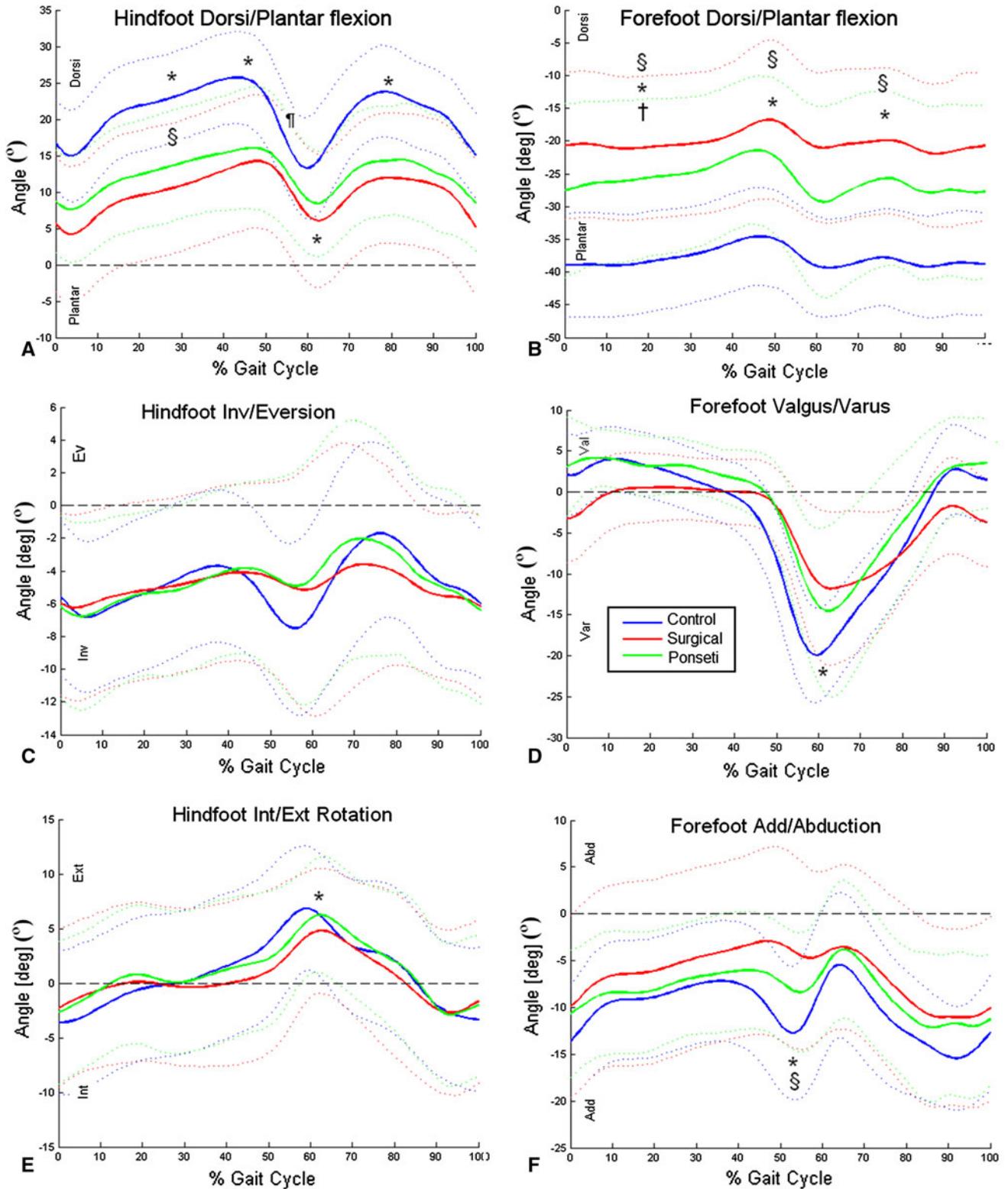


Fig. 3A–F The graphs show (A) hindfoot and (B) forefoot dorsi-flexion and plantar flexion, (C) hindfoot inversion and eversion, (D) forefoot valgus and varus, (E) hindfoot internal and external rotation, and (F) forefoot adduction and abduction during one gait cycle. *Significant difference between surgical and control groups ($p < 0.05$); †significant difference between Ponseti and control

groups ($p < 0.05$); §significant difference between surgical and Ponseti groups ($p < 0.05$); significant difference among all groups ($p < 0.05$); solid lines = mean values; dotted lines = SD; Plantar = plantar flexion; Dorsi = dorsiflexion; Int = internal; Ext = external; Val = valgus; Var = varus; Abd = abduction; Add = adduction.

Discussion

Little is known about how comprehensive surgical release and the Ponseti method compare with one another at longer term, or how patients treated with these approaches differ in terms of foot function, foot biomechanics, or quality-of-

life from individuals who did not have clubfeet as a child. The findings of this study showed that both treatment groups have deficits compared with control subjects in foot ROM, ankle strength, and prevalence of osteoarthritis, but in some areas results are better for subjects in the Ponseti group. Gait analysis showed reduced ankle plantar flexion and power generation during preswing phase of the gait cycle in the surgical group and for quality-of-life comparisons pain was more prevalent in the surgical group compared with the Ponseti group. The remaining domains of the SF-36 were similar in both groups.

There were limitations in this study. First, there was no pretreatment clubfoot severity classification. The patients were treated before one was implemented. Second, the possibility of selection bias does exist in the design of this study. All subjects treated with the Ponseti method were treated at the University of Iowa Hospitals and Clinics where the treatment technique had been in practice for decades. The comprehensive surgically treated subjects were treated at the Shriners Hospitals for Children – Chicago where this technique was the standard of care for children in whom the conventional casting technique failed. The entire study population was drawn from the same Midwestern region. There was also a similar ratio of gender between the participants and all subjects who met the inclusion criteria. Third, there is a question regarding how representative the groups are of the populations treated with each technique. The participants included were from a case series treated during the same study period and who were available for followup study. The populations were drawn from institutions that had specific standard treatment protocols for clubfoot, one for surgical treatment and one for Ponseti treatment.

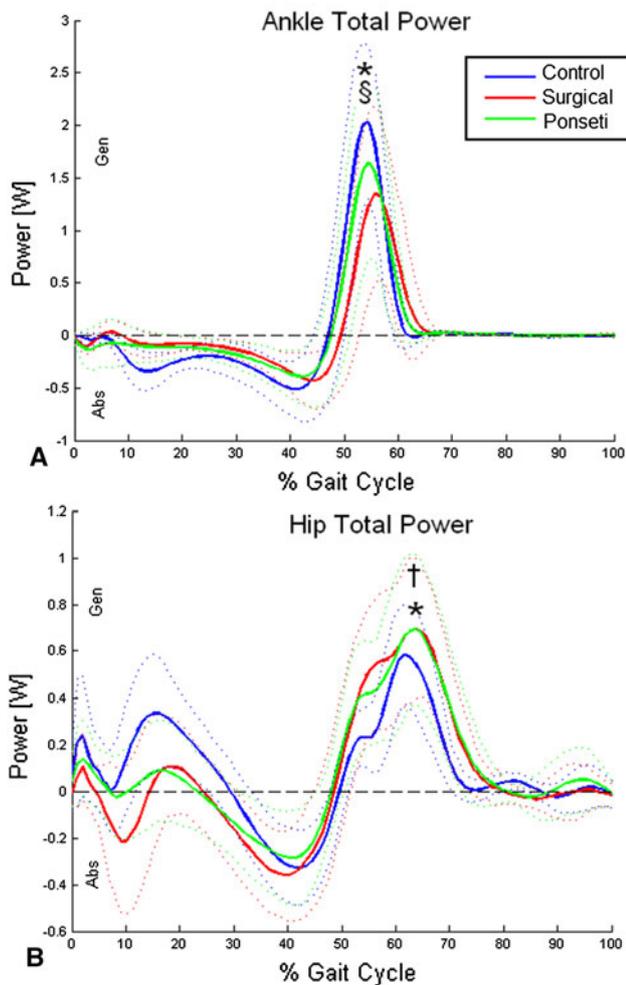


Fig. 4A–B (A) Ankle and (B) hip total power over one gait cycle are shown.*Significant difference between surgical and control groups ($p < 0.05$); †significant difference between Ponseti and control groups ($p < 0.05$); §significant difference between surgical and Ponseti groups ($p < 0.05$); solid lines = mean values; dotted lines = SD; Abs = absorbed; Gen = generated.

Physical and Radiographic Examination

Limited hindfoot motion appears to be a fundamental feature of clubfoot independent of treatment. Our findings of decreased ankle dorsiflexion and hindfoot inversion and eversion in the Ponseti and surgical groups compared with the control group support this; however, the Ponseti method preserves much greater ankle plantar flexion ROM, which is important for long-term function. Cooper and Dietz also identified decreased ROM in clubfeet treated

Table 5. American Orthopaedic Foot and Ankle Society ankle-hindfoot and midfoot scores

Score	Surgical group	Ponseti group	Control group	p values surgical versus control group	p values Ponseti versus control group	p values surgical versus Ponseti group
Ankle-hindfoot score (points)	78.8*†	85.9*†	99.7	< 0.0001	< .0001	0.0134
Midfoot score (points)	79.5*†	88.5*†	99.8	< 0.0001	< 0.0001	0.0070

* Significantly different from control group; † significant difference between Ponseti and surgical groups.

Table 6. SF-36 norm-based scores

SF-36 subscale	Surgical group	Ponseti group	Control group	p value surgical versus control group	p value Ponseti versus control group	p value surgical versus Ponseti group
Physical functioning	49.9*	51.8*	56.8	< 0.0001	< 0.0001	0.1719
Role-physical	50.4*	53.9	55.5	0.0009	0.0271	0.3065
Bodily pain	46.2* [†]	55.0 [†]	59.3	< 0.0001	0.0629	0.0080
General health	52.2*	54.1*	58.1	0.0009	0.0137	0.5392
Vitality	55.3	55.6	56.0	0.8190	0.6578	0.6917
Social functioning	52.6*	55.0	56.1	0.0115	0.3495	0.2430
Role-emotional	51.4	53.0	53.2	0.5531	0.7507	0.8387
Mental health	51.6	52.2	54.5	0.1323	0.1885	0.8864
Physical component summary	48.9	54.4	58.3			
Mental component summary	53.6	53.4	53.3			

* Significantly different from control group; [†]significant difference between Ponseti and surgical groups.

Table 7. International Clubfoot Study Group scores

Score	Number of feet	
	Surgical group (n = 37 feet)	Ponseti group (n = 29 feet)
Excellent	4 (11%)	8 (29%)
Good	18 (49%)	15 (51%)
Fair	14 (38%)	4 (14%)
Poor	1 (2%)	2 (6%)

with the Ponseti method, specifically a residual varus deformity of the subtalar joint [5]. The plantar flexor weakness observed particularly in the subjects in the surgical group is further supported by Karol et al. who identified a 27% difference in isokinetic strength of the surgically corrected clubfoot when compared with the unaffected side at 10 years followup [18]. Explanations for such weakness include surgically lengthened musculotendinous units [7], histologic changes at the muscular level [10], and abnormal foot and ankle biomechanics [2]. The radiographic findings in our study are consistent with those of Cooper and Dietz who reported “only minimum signs of early degenerative osteoarthritis” in 35% of feet with the Ponseti treatment at 30 years followup [5]. Dobbs et al. found a high rate of foot and ankle arthritis (56%) at 31 years followup of subjects who had surgical treatment [11]. For our study of a slightly younger cohort, osteoarthritis was only beginning to appear but was not prevalent.

Gait Analysis

To our knowledge, direct comparisons of the gait parameters of the Ponseti and surgical groups in the current study were

not done before. However, surgically treated subjects at 10 years followup [18], and adults treated using the Ponseti method [5] were found to have reductions in foot and ankle ROM during the stance phase of gait. We did not find a reduction in ankle dorsiflexion during terminal stance but did find a significant lack of ankle plantar flexion during preswing for the surgical group. A more detailed evaluation of the sagittal plane kinematics using a multisegment Milwaukee Foot Model identified overall flattening of the foot in both treatment groups with persistent hindfoot plantar flexion and compensatory increased dorsiflexion of the forefoot segment throughout the gait cycle. Together, the atypical segmental kinematics contribute to the appearance of sufficient ankle dorsiflexion throughout stance phase. Such segmental kinematic deviations also were identified by Theologis et al. who described increased midfoot dorsiflexion in children surgically treated for clubfoot [34], but we did not find that the mild foot drop described in their study persisted in our adult population. However, in our surgical group we did find reduced ankle power generation during preswing (push off) as described by Theologis et al. The lack of ankle push off power may be attributed to several factors including stiffness which prevents the joint from rapidly plantar flexing during preswing, muscle weakness limiting the torque acting around the joint, and abnormal foot structure which could inhibit the transfer of forces through the foot. If the subtalar joint has limited motion, or abnormal structure, this would restrict its ability to act as a “torque converter” as described by Inman et al. [16].

Quality-of-life Measures

The long-term impact of clubfoot treatment also was examined using well-established quality-of-life measures. The Ponseti and surgical groups showed diminished

hindfoot and midfoot scores compared with normal, and the surgical group was significantly worse than the Ponseti group. Bodily pain was greater for subjects in the surgical group than in the Ponseti group and control subjects as measured by the SF-36. The SF-36 pain scores for subjects in the surgical group were close to the normative value (50) for all adults, but when compared with the control group of healthy young adults, were significantly worse. This finding is consistent with the study by Hsu et al. of surgically treated individuals [15], but differs from the study of Dobbs et al. who measured all of the SF-36 scales below the normative data mean for a surgically treated population [11]. Cooper and Dietz identified specific areas of pain around the ankle, along the plantar fascia, under the metatarsal heads and at the Achilles insertion at 30 years followup [5].

Although various sources of pain are described for adults with clubfoot, we did not differentiate and the foot was not palpated for tenderness during the examination. We found no other reports of the International Clubfoot Study Group scores for these adult populations but we believe this measure provides a good basic summary of the long-term results of the two clubfoot treatments. For the surgical group, 87% scored good to fair, and for the Ponseti group, 80% scored excellent to good. In general, our outcome results of young adults with a comprehensive surgical release are better than those of another series using various release methods [11], but still inferior to clubfeet treated without joint release surgery.

Our study showed that the biomechanical function and long-term outcomes of young adults treated with the Ponseti method more closely compare with function of individuals without clubfoot than to those treated using a comprehensive surgical method. Differences were observed in ROM, strength, and pain; however, subjects in the Ponseti and surgical groups remained functional with a high quality of life. Our study supports efforts to correct clubfoot with Ponseti casting and minimize surgery to the joints, and highlights the need to improve methods that promote ROM and strength which are important for adult function. Future studies could examine the underlying tissue properties of the clubfoot, the biomechanics of casting correction, and longer-term rehabilitation implications on segmental foot ROM, strength, and pain.

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