Gait Analysis after Initial Nonoperative Treatment for Clubfeet

Intermediate Term Followup at Age 5

Lori A. Karol MD, Kelly Jeans MS, Ron ElHawary MD

Published online: 22 January 2009

© The Association of Bone and Joint Surgeons 2009

Abstract We conducted gait analysis following initial nonoperative clubfoot treatment to compare lower extremity kinematic (eg, ankle motion) and kinetic (eg, ankle power) characteristics between patients treated as infants with Ponseti casting or French physical therapy. This is a followup report of gait characteristics at age 5 years in patients who had previously been tested at age 2 years. One hundred-twenty five clubfeet in 90 patients (34 feet only Ponseti treatment, 40 only French PT, and 51 feet initial nonoperative treatment followed by surgery) were included. The gait characteristics were compared to those of age-matched normal control subjects. Ankle equinus during gait occurred in 5% of feet treated with the French method and none of those treated by the Ponseti method. Increased stance phase ankle dorsiflexion persisted in 24% of feet treated by the Ponseti method. Intoeing was seen in $\frac{1}{3}$ of both the French and Ponseti methods. Ankle push-off power was decreased compared to normal in patients treated by both methods, and even more so in operated feet. The presence or absence of Achilles

tenotomy did not affect ankle power. Gait characteristics of feet that did not have surgery and maintained correction were superior to those of operated feet.

Introduction

Over the last decade, there has been an increasing trend in the use of nonoperative techniques for the treatment of idiopathic clubfoot [24, 25]. The Ponseti method has been adopted throughout the world, and has resulted in fewer patients undergoing full posteromedial releases [1, 8, 22, 24, 29]. The Ponseti technique consists of weekly manipulations of the foot and application of long-leg casts, emphasizing external rotation of the foot, followed by a percutaneous tenotomy of the Achilles tendon in the majority of babies [25, 26, 28]. Long-term bracing with a foot abduction orthosis is a mandatory and important part of the Ponseti program.

The French physical therapy program continues to be utilized in parts of Europe as an alternative nonoperative treatment for babies with clubfeet [4, 12, 20]. This program entails daily sessions of physical therapy to manipulate the foot, followed by taping the foot daily in the corrected position. Correction of the adductus and varus is usually obtained in the first few months of life, however equinus has persisted in some feet [28]. This has led to the recent inclusion of either tenotomy or gastrosoleus recession in feet resistant to full correction. Foot abduction orthoses are not used in this method.

The literature is replete with early reports of the success of obtaining correction via the Ponseti technique from various centers [1, 6–9, 13, 15–17, 21, 22, 27, 30, 31]. Recurrence reportedly occurs in 32% to 41% of clubfeet [7, 13, 16], leading to further manipulation and casting, or in

Each author certifies that he or she has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.

Each author certifies that his or her institution has approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

L. A. Karol (✉), K. Jeans
Texas Scottish Rite Hospital for Children, 2222 Welborn, Dallas,
TX 75210, USA
e-mail: lori.karol@tsrh.org

R. ElHawary
Isaac Walton Killam Health Centre, Halifax, NS, Canada

severe cases, to surgical release. Success is reported as the ability to obtain correction without surgery [17, 22, 26, 29]. Likewise, reports from Bensahel et al. [4] and Dimeglio et al. [12] demonstrate the correction may be obtained with the French technique. Few reports of radiographic results are present in the literature [14, 27, 28], with even fewer reports of functional outcomes following treatment [14].

In 2008, our institution reported the gait characteristics of 105 2-year-old patients (154 feet) treated nonoperatively for clubfoot using instrumented motion analysis [14]. The data suggested 15% of the feet treated with the French physical therapy program had residual ankle equinus during stance phase, and 19% had a subtle foot drop in swing phase. Additionally, 44% had internal foot progression angles. In patients treated with the Ponseti method, 48% had excessive stance phase ankle dorsiflexion, and 10% a calcaneus gait, with inability to push off at terminal stance phase. Intoeing, as documented by foot progression angle, was present in 24% of feet casted with the Ponseti method. Due to the small size of the children and therefore their small step lengths, kinetic data could not be obtained as they could not strike the force plates cleanly at this age.

Our purposes were to (1) describe differences in sagittal and transverse plane motions between patients treated by the Ponseti, French, or surgical methods to those motions in normal subjects; (2) describe differences in moments and power between the three groups and normal subjects; and (3) compare ankle power in patients who did and did not have Achilles tenotomy.

Materials and Methods

We prospectively followed 90 patients (125 clubfeet) treated in infancy and studied in our gait analysis laboratory at 5 years of age. These were taken from the earlier reported group of 182 patients (273 feet) [14]. Due to the increased size of the children resulting in increased step lengths, kinetic data (ie, ankle and hip power generation) could now be compared between the two treatment methods, age-matched children with normal feet, and patients who had surgical correction. These patients were initially treated from 1998 to 2002. We determined the severity of the clubfoot deformity at presentation using the scale of Dimeglio et al. [11], which rates feet from 0 (normal) to 20 (rigid) points. We included only clubfeet with a minimum score of 10 and a maximum score of 17. During the time of the study 13 patients had a score less than 10 or greater than 17. We also excluded patients with teratologic clubfeet and those who had undergone previous treatment outside our facility. Of these 125 clubfeet, 34 had been treated with the Ponseti method; 23 had percutaneous tendoachilles tenotomy, while 11 did not. Forty feet were

treated with the French method, six of which had undergone tendoachilles lengthening or tenotomy. Fifty-one feet had undergone initial treatment with PT or Ponseti casting, yet eventually required surgeries, including posterior ($n = 17$) or posteromedial release ($n = 23$), tibialis anterior transfer ($n = 5$), and/or tibial rotational osteotomy ($n = 8$). Surgery was performed at an average age of 2.3 years (range, 0.75–5.3 years).

The average score of Dimeglio et al. [11] for the three groups was 12.8 (range, 10–15) for the feet treated with the Ponseti method, 12.9 (range, 10–17) for those treated with the French method, and 14.1 (range, 10–17) for those feet that had undergone a surgery. There was no difference ($p > 0.05$) in initial severity of deformity as rated by the score of Dimeglio et al. [11] between the nonsurgical feet treated with the French PT method versus the Ponseti method, however feet that eventually required surgery were initially more severe ($p = 0.0002$) than those that did not.

At the initial visit, both the Ponseti method and the French physical therapy method were described in detail to the parents. Randomization into the two treatment programs was not possible due to the transportation requirements inherent in the daily physical therapy program. Therefore, the parents were asked to choose the method of treatment. Patients in the casting program underwent weekly manipulation and application of long-leg casts, adhering to the protocol of Ponseti [17, 18]. In 23 of 34 patients (68%), a percutaneous Achilles tenotomy was performed prior to the last cast. Upon removing the cast, the babies were fit with a foot abduction orthosis for 3 months full time, and then for nighttime wear until age 2 to 3 years. Patients in the French physical therapy program underwent daily therapy sessions 5 days per week to mobilize the foot, with taping of the foot between sessions in the corrected position. Upon correction of the foot, various orthoses may be fabricated to maintain correction, but a foot abduction orthosis is not prescribed. Until recently, heel cord tenotomy was not performed in babies treated by the French method, although six of the 40 French-treated clubfeet (15%) did have tenotomy.

Patients underwent gait analysis at age 5 years. Kinematic data were collected with a Vicon motion capture system (Vicon, Oxford, UK) during walking at a self-selected speed along a 15-meter walkway using a standard marker set. Foot markers were not used due to the small size of the children's feet. Data were analyzed using Vicon clinical manager software. Force data were collected from footstrikes upon AMTI forceplates (Advanced Mechanical Technology, Inc., Watertown, MA). Kinematic and kinetic data were obtained from 17 normal 5-year-old subjects for comparison. Kinematic parameters that were greater than one standard deviation from age-matched normal control data were noted. This allowed comparison and consistency

Table 1. Definitions of criteria used for kinematic and kinetic gait deviations from normal

Measure	Abnormal gait criteria
Equinus	< 3° of dorsiflexion (DF) during stance
Increased DF	> 16° of DF in stance
Calcaneus	< 7° of plantarflexion (PF) at toe off
Foot drop	> 9° of PF during the last 25% of swing
Shank/foot rotation (int)	< 0° average external rotation during stance
Foot progression (int)	> 5° average internal rotation during stance
Hip rotation (ext)	> 4° averaged external rotation during stance
Hip power (inc)	> 1.42 Watts/kg
Ankle moment (dec)	< 0.83 Nm/kg
Ankle power (dec)	< 2.19 Watts/kg

with previous reports of gait analysis in clubfoot patients at age 2 from our center [14]. Ankle equinus, increased ankle dorsiflexion, foot drop, and calcaneus at age 5 years were defined (Table 1). An internal foot progression angle was defined as foot position greater than 0° internal during stance phase. Peak ankle power at push off was taken from the sagittal plane ankle power graph, and compared between groups. Decreased sagittal ankle power was defined as power that was less than one standard deviation from normal values and was less than the lowest value obtained from the normal subjects. Calcaneus was defined as less than 7° of plantarflexion at terminal stance phase, which was the least amount of plantarflexion at pushoff seen in the 17 control 5-year-old subjects.

Comparisons in ankle dorsiflexion, foot drop, internal foot progression angle, and ankle power generation were made between the three treatment groups, as well as with control data using two-way repeated measures (two-way ANOVA). A post-hoc Tukey test was then performed to determine specific differences. A comparison between ankle power in patients with and without heel cord tenotomy was also made using a Student t-test. Chi-square testing was used to compare the distributions of proportions between the groups. Analysis was performed with SAS version 9.1 (SAS Institute Inc., Cary, NC).

Results

The average stance-phase dorsiflexion did not differ between groups and between clubfeet and control subjects at age 5 years (Table 2, Fig. 1). Stance phase equinus, defined as less than 3° of dorsiflexion during midstance phase, was present in two feet following the French therapy treatment (5%), in three surgical feet (6%), but in no feet following Ponseti treatment (Table 3). Foot drop in swing

Table 2. Average kinematic data in degrees ($\pm$ standard deviation) following Ponseti and French treatment, compared to surgical patients and age-matched controls

Treatment group	# Feet	Sagittal plane ankle motion				Transverse plane			
		PF Initial contact	DF Midstance	PF Push off	DF End of swing	Total ROM (stance+swing)	Hip rotation	Shank/foot rotation	Foot progression
Ponseti	34	7.2 ($\pm$ 4.1)	12.5 ($\pm$ 4.2)	15.4 ($\pm$ 6.7)	0.2 ($\pm$ 5.5)	30.1 ($\pm$ 5.9)	7.2 ext ($\pm$ 8.2)	4.0 int ($\pm$ 9.1)	0.4 ext ($\pm$ 8.6)
French	40	6.3 ($\pm$ 3.4)	10.4 ($\pm$ 4.0)	16.2 ($\pm$ 8.0)	0.8 ($\pm$ 5.6)	28.2 ($\pm$ 6.7)	4.6 ext ($\pm$ 8.4)	3.4 int ($\pm$ 9.9)	1.1 int ($\pm$ 7.5)
Surgical	51	7.3 ($\pm$ 5.3)	12.5 ($\pm$ 5.2)	12.7 ($\pm$ 5.9)	0.1 ($\pm$ 5.9)	27.2 ($\pm$ 4.7)	5.3 ext ($\pm$ 8.0)	6.1 int ($\pm$ 10.9)	5.7 int # ($\pm$ 8.9)
Normal	17	6.9 ($\pm$ 3.5)	12.1 ($\pm$ 4.3)	18.1† ($\pm$ 8.0)	0.7 ($\pm$ 4.3)	32.7 ³ ($\pm$ 6.5)	2.8 int ($\pm$ 7.2)	14.6 ext * ($\pm$ 7.9)	8.2 ext * ($\pm$ 4.4)

p < 0.05: * Normal < Ponseti/French/Surgical; # Surgical > Ponseti/Normal; † Normal > Surgical; ³ Normal > Surgical/French.

PF = ankle plantarflexion; DF = dorsiflexion; ROM = range of motion.

Total ROM measures the maximum amount of DF and the minimum amount of PF during the gait cycle.

phase was present in seven feet following the Ponseti method (21%), but in only two feet after French therapy (5%) and in eight surgical feet (16%). Increased stance-phase dorsiflexion was more frequent ($p = 0.015$) in the feet treated by the Ponseti method (eight feet, 24%) compared to the surgical feet (nine feet, 18%), and the French method (one foot, 3%). The percentage of patients with calcaneus was similar in all three methods (three feet [9%] for the Ponseti method; five feet [13%] for the French method, and four feet [8%] of surgically treated feet).

We commonly observed differences in transverse plane motions in all three patient groups compared to those of the control subjects (Tables 2, 3). A similar proportion of feet in both nonoperative treatment regimens had intoeing (12 feet [30%] treated by the French method versus 11 feet [32%] treated by the Ponseti method). An internal foot progression angle was seen in 26 (51%) feet that had

undergone surgery. In further analyzing transverse plane motions, an internal shank-based foot rotation, indicative of tibial torsion, internal calcaneopedal rotation, or forefoot adductus was seen in 29 feet (85%) treated by the Ponseti method, and 42 surgical feet (82%), but only 19 feet (48%) treated by the French method had internal shank-based foot rotation. The incidence of internal shank-based foot rotation in the feet treated by the French physical therapy program was decreased ($p < 0.001$) compared to that in the feet treated by the Ponseti method. Twenty-four limbs (71%) in patients treated by the Ponseti method and 19 limbs (48%) in patients treated with the French method demonstrated external hip rotation during stance ($p = 0.067$).

Kinetic data failed to distinguish between treatment groups (Table 4). A decreased stance-phase ankle dorsiflexion moment was seen in 23 feet (72%) treated by the Ponseti method, 28 feet (74%) treated by the French method, and 36 surgical feet (75%). Similarly, decreased ankle power generation at pushoff was present in 15 feet

Fig. 1 Averaged sagittal plane ankle motions for Ponseti (solid), French (dotted) and surgical (dashed) treated clubfeet at 5 years of age were compared to age-matched controls (thick grey band). Positive values are dorsiflexion (DF) and negative values are plantarflexion (PF). Average motions of all three clubfoot groups fall within normal range for ankle motion during gait.

Table 4. A comparison of the rate of occurrence of decreased ankle moment, decreased ankle power, and increased hip power for the Ponseti, French and surgical groups

Treatment group	# Feet	Kinetics		
		Ankle and hip		
		Ankle moment (dec)	Ankle power (dec)	Hip power (inc)
Ponseti	32	72%	47%	28%
		23	15	9
French	38	74%	53%	42%
		28	20	16
Surgical	48	75%	67%	35%
		36	32	17

Table 3. A comparison of the rate of occurrence of identified abnormality within groups: Ponseti, French and surgical

Treatment group	# Feet	Kinematics							
		Sagittal plane ankle motion					Transverse plane		
		Equinus (stance)	Foot drop (swing)	Increased dorsiflexion (stance)	Calcaneus (stance)	Normal sagittal ankle	Shank/foot rotation (int)	Hip rotation (ext)	Foot progression (int)
Ponseti	34	0%	21% +	24%^	9%	53%	85%	71%^	32%
		0	7	8	3	18	29	24	11
French	40	5%	5%	3%	13%	75%	48%§	48%	30%
		2	2	1	5	30	19	19	12
Surgical	51	6%	16%	18%	8%	59%	82%	49%	51%
		3	8	9	4	30	42	25	26

$p < 0.05$: [^] Ponseti > French/Surgical; [§] French < Ponseti/Surgical; + Ponseti > French.

Table 5. Group comparison: average kinetic data ($\pm$ standard deviation) following Ponseti and French treatments, compared to surgical patients and age matched controls

Treatment group	# Feet	Ankle moment (Nm/kg)	Ankle power (W/kg)	Hip power (W/kg)
Ponseti	32	0.74 ($\pm$ 0.11)	2.36 ($\pm$ 0.71)	1.38 ($\pm$ 0.44)
French	38	0.76 ($\pm$ 0.14)	2.21 ($\pm$ 0.83)	1.47 κ ($\pm$ 0.57)
Surgical	48	0.75 ($\pm$ 0.13)	1.97 ($\pm$ 0.62)	1.40 ($\pm$ 0.60)
Normal	17	0.95 [‡] ($\pm$ 0.12)	2.83 ³ ($\pm$ 0.64)	1.04 ($\pm$ 0.38)

$p < 0.05$: [‡] Normal > Ponseti/French/Surgical; ³ Normal > Surgical/French; κ French > Normal.

Fig. 2 Averaged sagittal plane ankle power for Ponseti (solid), French (dotted) and surgical (dashed) treated clubfeet at 5 years of age were compared to age-matched controls (thick grey band). Positive values are power generation (Gen) and negative values are power absorption (Abs). All three clubfoot groups are at the lower limit of normal for mean push-off power generation during gait.

Fig. 3 Averaged sagittal plane hip power for Ponseti (solid), French (dotted) and surgical (dashed) treated clubfeet at 5 years of age were compared to age-matched controls (thick grey band). Positive values are power generation (Gen) and negative values are power absorption (Abs). Hip power generation at terminal stance and early swing (vertical line at mid-gait cycle) is at the upper limit of normal for all three clubfoot groups.

(47%) treated by the Ponseti method, 20 feet (53%) treated by the French method, and 32 surgical feet (67%). The average ankle power was similar in feet treated by the Ponseti method, the French method, and those treated surgically (Table 5, Fig. 2). Ankle power was greater ($p < 0.001$) in normal feet compared to the French and surgical groups. The hip power at the transition from stance to swing phase in children with clubfeet (Fig. 3) was similar ($p = 0.054$) to that in our normal population.

Patients with feet that had undergone Achilles tenotomy ($n = 28$) had similar ($p = 0.223$) ankle power to those that did not ($n = 42$).

Discussion

With the increasing popularity of nonoperative treatment for babies with clubfeet, it is important to know that the functional result, i.e. how the children walk, is at least as good, if not better, than that achieved with traditional surgical methods. While the results at age 2 were promising, it is important to evaluate the children throughout

growth. Therefore, at age 5, the kinematic and kinetic characteristics of the limbs treated with the two methods either in isolation or with subsequent surgery should be studied to evaluate the merit of these treatment regimens. Additionally, it is not known if Achilles tenotomy produces a deleterious effect on ankle function. Through gait analysis, this can be studied.

There are some limitations to this that require discussion. First and foremost, the likelihood of a child not walking in their “normal” fashion while undergoing instrumented gait analysis is questionable. Our experience in testing very young children in a nonthreatening environment with parents present and distractions such as toys available allows as natural a testing session as possible. Also, a miscalculation of true ankle equinus during gait due to dorsiflexion through the midfoot is possible, but careful scrutiny of the videotapes is performed to attempt to minimize this error. Segmental foot markers would enhance the accuracy of the data, but at age 5 years, the foot is too small to allow such minute analysis. Later studies at age 10 years are planned to analyze segmental foot motion. Finally, the threshold for what is considered

pathologic in pediatric gait versus what is functionally important in the everyday activities of a child, is controversial. In our earlier study [14] we used a threshold beyond one standard deviation to define abnormal but we have no evidence that threshold has any functional importance.

Our data suggest the majority of children have satisfactory gait following nonoperative treatment of clubfeet. A minority of patients who have not required surgery have persistent gait deviations at age 5, with a small number of the French PT (5%) feet having equinus and a small number of feet treated by the Ponseti method (24%) having excessive dorsiflexion during stance phase. Sagittal plane gait deviations were seen less frequently in the 5-year-olds compared to data gathered from the same patients at age 2 years [14]. In patients treated by the French method, equinus was seen less frequently at age 5 years (5%) compared to age 2 years (15%). This may be due to the fact that three of the children who exhibited ankle equinus at age 2 years have subsequently undergone surgery between the ages of 2 and 5 years and are therefore now in the surgical group at age 5 years. We now perform earlier tendoachilles tenotomy in children treated by the French method with the expectation of decreasing the number of young children with ankle equinus, and decreasing the likelihood of further surgery during childhood for persistent lack of dorsiflexion.

Excessive ankle stance-phase dorsiflexion is still seen most frequently at age 5 years in patients treated by the Ponseti method compared to those treated by the French method, but the overall incidence has decreased from 48% at age 2 to 24% at age 5 in patients treated by the Ponseti method. Increased dorsiflexion was associated with decreased ankle push-off power in patients treated by the Ponseti method. Those with excessive dorsiflexion had an average 14% less push-off power generation compared to those with normal dorsiflexion during stance phase. While the decrease in power is less at age 5, the data support continuing diminished mechanical efficiency of the ankle during walking.

Residual intoeing has been widely reported in the literature in gait studies of clubfeet [5, 10, 18, 19, 23, 32, 33]. An interesting finding was seen in the transverse plane in our children at age 5. Approximately 30% of patients in both nonsurgical groups demonstrated persistent intoeing on gait analysis. The prior study at age 2 reported a higher incidence of intoeing (44%) in the patients treated by the French method compared to the Ponseti method (24%) [14]. There are two possible explanations for the decrease in intoeing in the French-treated patients and increase in intoeing in the patients treated by the Ponseti method. First, patients with obvious intoeing at age 2 may have undergone tibial osteotomy, tibialis anterior tendon transfer, or

lateral column shortening between the ages of 2 and 5 years old, thereby decreasing the overall number of children with intoeing at the later study. This was the case for six patients initially treated by the French method who had not had surgery at the time of their initial gait analysis at age 2, but who are now in the surgical group at age 5. A second possible explanation relates to the timing of discontinuation of the foot abduction orthosis in the patients treated by the Ponseti method. We routinely recommend use of the orthosis until age 2 to 3 years. At age 5 years, all children sleep without bracing. Therefore, it is possible subtle internal rotation of the foot might result at the later age. We found 85% of patients treated by the Ponseti method had an internal shank-based foot rotation at age 5, and that many of these children walked with external rotation at the hip to compensate for the more distal internal rotation and thereby balance the overall foot progression angle. The presence of increased external rotation of the hip during gait has been previously documented in children with clubfoot by Theologis et al. [32].

The diminished ankle power generation is similar to that seen at 10-year followup after posteromedial release [18]. In that study, ankle plantarflexion power was decreased by 23% compared to the uninvolved contralateral ankle in asymptomatic children who had undergone posteromedial release. In the current study, plantarflexion power was compared to age-matched normal values rather than the contralateral foot. (This allowed the inclusion of subjects with bilateral clubfeet.) Ankle power generation was decreased 17% in at 5 years in patients treated by the Ponseti method, 22% in patients treated by the French method, and 30% in feet treated surgically compared to age-matched controls. While those feet successfully treated without surgery have greater power than the operated group, clearly this study, as well as other previous publications, supports an association between clubfoot and diminished ankle power [3, 10, 18, 23, 32]. Power is affected by both range of motion and muscle strength. While some of the feet treated by the Ponseti protocol had excessive dorsiflexion, typically the ankle of a patient with clubfoot has diminished range of motion, which will lead to a decrease in power generation. Additionally, it is well known that the gastrosoleus muscle itself is smaller in bulk in patients with clubfeet, which may result in relative weakness and reduced ankle power. It will be interesting to measure isokinetic gastrosoleus strength in these patients as they grow older and to compare their strength with their ankle power as well.

Previous literature reported that the hip may be compensating for the lack of ankle push-off power. Alkjaer et al. [2] previously reported reduced ankle moments and work, and increased hip joint moments in patients who had undergone surgery for treatment of clubfoot at an average

19-year followup. Although the average hip power generation was greater in all three treatment groups than control data, we were unable to document a statistically significant increase in our 5-year-old clubfoot patients.

While increased dorsiflexion was associated with heel cord tenotomy in the younger children, this relationship was not seen in the 5-year-old data. Also, ankle power generation was not greater in those children who did not have a tenotomy compared to those who did. It appears that Achilles tenotomy, when needed for the correction of equinus in patients treated with the Ponseti method, does not lead to a less efficient gait and ankle push-off, although diminished compared to normal, is not worsened by the tenotomy by age 5 years.

Sagittal plane ankle motion data show improvement at age 5 compared to previously reported data at age 2 years [14] in patients treated nonoperatively for clubfoot with either physical therapy or the Ponseti method. At age 5, ankle equinus is seen less frequently in those children treated by the French method without surgery, and increased ankle dorsiflexion is less prevalent in patients treated by the Ponseti method. Internal foot progression persists in approximately 30% of nonoperated clubfeet at age 5, but external hip rotation may mask the internal rotation in many children. Kinetic ankle data has demonstrated lack of efficiency of the ankle plantar flexors compared to normal, but improved power compared to surgically treated feet. Overall, gait analysis data at age 5 supports continued efforts to treat clubfeet nonoperatively.

Acknowledgments We thank Richard Browne, PhD, for his assistance with statistical analysis, Patricia Bush and Cindy Daniel for research administrative assistance, and Vy Do for her help processing and preparing gait data for review.

References

1. Abdelgawad AA, Lehman WB, van Bosse HJ, Scher DM, Sala DA. Treatment of idiopathic clubfoot using the Ponseti method: minimum 2-year follow-up. *J Pediatr Orthop B*. 2007;16:98–105.
2. Alkjær T, Pedersen EN, Simonsen EB. Evaluation of the walking pattern in clubfoot patients who received early intensive treatment. *J Pediatr Orthop*. 2000;20:642–647.
3. Aronson J, Puskasich CL. Deformity and disability from treated clubfoot. *J Pediatr Orthop*. 1990;10:109–119.
4. Bensahel H, Guillaume A, Czukonyi Z, Desgrippes Y. Results of physical therapy for idiopathic clubfoot: a long-term follow-up study. *J Pediatr Orthop*. 1990;10:189–192.
5. Beyaert C, Haumont T, Paysant J, Lascombes P, Andre JM. The effect of inturning of the foot on knee kinematics and kinetics in children with treated idiopathic clubfoot. *Clin Biomech*. 2003;18:670–676.
6. Bouchoucha S, Smida M, Saïed W, Safi H, Ammar C, Nessib MN, Ghachem MB. Early results of the Ponseti method using the Steenbek foot abduction brace: a prospective study of 95 feet. *J Pediatr Orthop B*. 2008;17:134–138.
7. Changulani M, Garg NK, Rajagopal TS, Bass A, Nayagam SN, Sampath J, Bruce CE. Treatment of idiopathic club foot using the Ponseti method. Initial experience. *J Bone Joint Surg Br*. 2006;88:1385–1387.
8. Cooper DM, Dietz FR. Treatment of idiopathic clubfoot. A thirty-year follow-up note. *J Bone Joint Surg Am*. 1995;77:1477–1489.
9. Cosma D, Vasilescu D, Valeanu M. Comparative results of the conservative treatment in clubfoot by two different protocols. *J Pediatr Orthop B*. 2007;16:317–321.
10. Davies TC, Kiefer G, Zernicke RF. Kinematics and kinetics of the hip, knee, and ankle of children with clubfoot after posteromedial release. *J Pediatr Orthop*. 2001;21:366–371.
11. Dimeglio A, Bensahel H, Souchet P, Mazeau P, Bonnet F. Classification of clubfoot. *J Pediatr Orthop B*. 1995;4:129–136.
12. Dimeglio A, Bonnet F, Mazeau P, De Rosa V. Orthopaedic treatment and passive motion machine: consequences for the surgical treatment of clubfoot. *J Pediatr Orthop B*. 1996;5:173–180.
13. Dobbs MB, Rudzki JR, Purcell DB, Walton T, Porter KR, Gurnett CA. Factors predictive of outcome after use of the Ponseti method for the treatment of idiopathic clubfeet. *J Bone Joint Surg Am*. 2004;86:22–27.
14. El-Hawary R, Karol LA, Jeans KA, Richards BS. Gait analysis of children treated for clubfoot with physical therapy or the Ponseti cast technique. *J Bone Joint Surg Am*. 2008;90:1508–1516.
15. Gul A, Sambandam S. Results of manipulation of idiopathic clubfoot deformity in Malawi by orthopaedic clinical officers using the Ponseti method: a realistic alternative for the developing world? *J Pediatr Orthop*. 2007;27:971–972.
16. Haft GF, Walker CG, Crawford HA. Early clubfoot recurrence after use of the Ponseti method in a New Zealand population. *J Bone Joint Surg Am*. 2007;89:487–493.
17. Herzenberg JE, Radler C, Bor N. Ponseti versus traditional methods of casting for idiopathic clubfoot. *J Pediatr Orthop*. 2002;22:517–521.
18. Karol LA, Concha MC, Johnston CE 2nd. Gait analysis and muscle strength in children with surgically treated clubfeet. *J Pediatr Orthop*. 1997;17:790–795.
19. Karol LA, O'Brien SE, Wilson H, Johnston CE, Richards BS. Gait analysis in children with severe clubfeet: early results of physiotherapy versus surgical release. *J Pediatr Orthop*. 2005;25:236–240.
20. Masse P. Le traitement du pied bot par la methode “fonctionnelle”, in Cahier d'enseignement de la SOFCOT. Paris, France: Expansion Scientific; 1977;3:51–56.
21. Morcuende JA, Abbasi D, Dolan LA, Ponseti IV. Results of an accelerated Ponseti protocol for clubfoot. *J Pediatr Orthop*. 2005;25:623–626.
22. Morcuende JA, Dolan LA, Dietz FR, Ponseti IV. Radical reduction in the rate of extensive corrective surgery for clubfoot using the Ponseti method. *Pediatrics*. 2004;113:376–380.
23. Muratli HH, Dagli C, Yavuzer G, Celebi L, Bicimoglu A. Gait characteristics of patients with bilateral club feet following posteromedial release procedure. *J Pediatr Orthop B*. 2005;14:206–211.
24. Noonan KJ, Richards BS. Nonsurgical management of idiopathic clubfoot. *J Am Acad Orthop Surg*. 2003;11:392–402.
25. Ponseti IV. *Congenital Clubfoot: Fundamentals of Treatment*. Oxford, England: Oxford University Press; 1996.
26. Ponseti IV. The Ponseti technique for correction of congenital clubfoot. *J Bone Joint Surg Am*. 2002;84:1889–1890.

27. Radler C, Manner HM, Suda R, Burghardt R, Herzenberg JE, Ganger R, Grill F. Radiographic evaluation of idiopathic clubfeet undergoing Ponseti treatment. *J Bone Joint Surg Am.* 2007;89:1177–1183.
28. Richards BS, Johnston CE, Wilson H. Nonoperative clubfoot treatment using the French physical therapy method. *J Pediatr Orthop.* 2005;25:98–102.
29. Scher DM. The Ponseti method for treatment of congenital club foot. *Curr Opin Pediatr.* 2006;18:22–25.
30. Shack N, Eastwood DM. Early results of a physiotherapist-delivered Ponseti service for the management of idiopathic congenital talipes equinovarus foot deformity. *J Bone Joint Surg Br.* 2006;88:1085–1089.
31. Sud A, Tiwari A, Sharma D, Kapoor S. Ponseti's vs. Kite's method in the treatment of clubfoot—a prospective randomized study. *Int Orthop.* 2008;32:409–413.
32. Theologis TN, Harrington ME, Thompson N, Benson MK. Dynamic foot movement in children treated for congenital talipes equinovarus. *J Bone Joint Surg Br.* 2003;85:572–577.
33. Yngve DA. Foot-progression angle in clubfeet. *J Pediatr Orthop.* 1990;10:467–472.