Part 1 of 2

Summary of the Attached Published Articles on the Ponseti Method

(from the most recent to oldest articles)

Published Articles

Morcuende, J; Ponseti I.V.; **Radical Reduction in the Rate of Extensive Corrective Surgery for Clubfoot Using the Ponseti Method**, Journal of Pediatrics, Volume 113 No 2 Feb 2004 University of Iowa

Lehman, Wallace; **A Method for the Early Evaluation of the Ponseti (Iowa) Technique for the Treatment of Idiopathic Clubfoot**, Journal of Pediatric Orthopedics B 2003, 12:133-140 NYU

Colburn, M; **Evaluation of the Treatment of Idiopathic Clubfoot by Using the Ponseti Method**; Journal of Foot and Ankle Surgery 42(5): 259-267, 2003 Kaiser Permanente Medical Center, Walnut Creek, California

Morcuende, J. Ponseti I.V.; **The Effect of the Internet in the Treatment of Congenital Idiopathic Clubfoot**, Iowa Orthopedic Journal, 2003: 83-86 University of Iowa

Herzenberg, J,; **Ponseti Versus Traditional Methods of Casting for Idiopathic Clubfoot**; Journal of Pediatric Orthopedics 22:517-521; 2002 Maryland Center for Limb Lengthening and Reconstruction, Baltimore, Maryland

Pirani, S.; **Magnetic Resonance Imaging Study of the Congenital Clubfoot Treated with the Ponseti Method,** Journal of Pediatric Orthopedics 21:719-726, 2001 Royal Columbian Hospital, New Westminster, British Columbia, Canada

Ponseti, I.V.; **Relapsing Clubfoot: Causes, Prevention and Treatment**, Iowa Orthopedic Journal, Vol. 22:55-56, 2002. University of Iowa (not a full copy of the article)

Ponseti, I.V.; **Editorial, Clubfoot Management**, Journal of Pediatric Orthopedics, vol. 20: 699-700, 2000, University of Iowa (not a full copy of the article)

Dobbs, M., Ponseti I.V.; **Treatment of Idiopathic Clubfoot: An Historical Review**; Iowa Orthopedic Journal, 2000, volume 20 pages 59 to 64, University of Iowa

Ponseti, I.V., **Current Concepts: Common Errors in the Treatment of Congenital Clubfoot**, International Orthopedics (SICOT) 1997, 21:137-141 University of Iowa

Dietz, F., **Treatment of Idiopathic Clubfoot, A Thirty Year Follow-Up Note**, Journal of Bone and Joint Surgery, Vol 77-A No 10 October 1995, pages 1477 – 1489 University of Iowa group 1 copies

Morcuende, J., Ponseti, I.V.; **Plaster Cast Treatment of Clubfoot: The Ponseti Method of Manipulation and Casting**, Journal of Pediatric Orthopedics Part B 3:161-167, 1994, University of Iowa

Ponseti, I.V., **Current Concepts Review: Treatment of Congenital Club Foot**, Journal of Bone and Joint Surgery, 1992 pages 448-454, University of Iowa

Group 2 copies

Ponseti, I.V., **A Radiographic Study of Skeletal Deformities in Treated Clubfoot**, Clinical Orthopedics, October 1981 Volume 160 pages 30 – 42, University of Iowa

Laaveg, S., Ponseti, I.V., **Long-Term Results of Treatment of Congenital Club Foot**, Journal of Bone and Joint Surgery, vol. 62-A No 1 January 1980, pages 23 – 31, University of Iowa

Ponseti, I.V.; **Congenital Club Foot: The Results of Treatment**, Journal of Bone and Joint Surgery, vol. 45-A No 2 page 261-275, March 1963, University of Iowa

Unpublished Articles

UNKNOWN AUTHOR, **The Ponseti Method of Clubfoot Treatment**

Penny, J.N., Kinematics of the Subtalar Joint. **How the Manipulation Method of Ponseti Works.** Approx 2004

Penny, J.N., Pirani, S., Morcuende, J., Schwentker, E. **The Ponseti method of Clubfoot Care: A Vision for the Developing World**. Approx 2003

Pirani, S., **A Method of Clubfoot Evaluation** Clubfoot Clinic of the Royal Columbian Hospital, University of British Columbia, B.C., Canada

Radical Reduction in the Rate of Extensive Corrective Surgery for Clubfoot Using the Ponseti Method

Jose A. Morcuende, MD, PhD; Lori A. Dolan, PhD(c); Frederick R. Dietz, MD; and Ignacio V. Ponseti, MD

ABSTRACT. ***Objectives.*** **The purpose of this study was to evaluate the efficacy of the Ponseti method in reducing extensive corrective surgery rates for congenital idiopathic clubfoot.**

Methods. **Consecutive case series were conducted from January 1991 through December 2001. A total of 157 patients (256 clubfeet) were evaluated. All patients were treated by serial manipulation and casting as described by Ponseti. Main outcome measures included initial correction of the deformity, extensive corrective surgery rate, and relapses.**

Results. **Clubfoot correction was obtained in all but 3 patients (98%). Ninety percent of patients required ≤5 casts for correction. Average time for full correction of the deformity was 20 days (range: 14–24 days). Only 4 (2.5%) patients required extensive corrective surgery. There were 17 (11%) relapses. Relapses were unrelated to age at presentation, previous unsuccessful treatment, or severity of the deformity (as measured by the number of Ponseti casts needed for correction). Relapses were related to noncompliance with the foot-abduction brace. Four patients (2.5%) underwent an anterior tibial tendon transfer to prevent further relapses.**

Conclusions. **The Ponseti method is a safe and effective treatment for congenital idiopathic clubfoot and radically decreases the need for extensive corrective surgery. This technique can be used in children up to 2 years of age even after previous unsuccessful nonsurgical treatment.** ***Pediatrics*** **2004;113:376–380;** ***clubfoot, Ponseti method.***

Congenital idiopathic clubfoot is a complex foot deformity that occurs in an otherwise normal child. In 1996, 2224 children were born with clubfoot in the United States, an incidence of ~0.6 cases per 1000 live births.[1] The goal of treatment is to correct all components of the deformity so that the patient has a pain-free, plantigrade foot with good mobility, without calluses, and without the need to wear special or modified shoes.

Most orthopedists agree that the initial treatment should be nonsurgical and started soon after birth. Many different methods of correction are used, most of them involving manipulation and casting. In many institutions, manipulation and serial casting require many months of treatment and frequently result in incomplete or defective corrections.[2–4] As a result, extensive corrective surgery is indicated in 50% to 90% of the cases, often with disturbing failures and complications.[5–11] In addition, depending on the technique followed and the residual deformity, up to 47% of clubfeet undergo 1 or more revision surgeries.[12–17]

The results at our institution differ radically from these reports. Since the late 1940s, we have followed the method of correction developed by the senior author.[18] This method involves weekly stretching of the deformity followed by application of a long-leg cast. All components of the deformity usually correct within 4 to 5 weeks with the exception of the equinus. A simple percutaneous tendoachilles tenotomy often is necessary to correct completely the equinus. The first report of 67 patients who were younger than 6 months and treated by the Ponseti method demonstrated satisfactory and rapid initial correction in the majority of cases (83%) with minimal complications.[19] However, there was a relatively high incidence clubfoot relapses (56%) in this patient population. Most relapses were treated successfully with repeat manipulation and castings and/or anterior tibial tendon transfers. More important, the long-term functional and clinical results at a 30-year follow-up were excellent or good using pain and functional limitation as the outcome criteria in the majority of these patients (78% compared with 85% of a matched control population born with normal feet).[20]

The technique has been refined over the years, and we have come to realize the necessity of hyperabduction of the foot in the last cast and long-term use of the foot abduction brace. In addition, our referral base has radically changed as a result of patient referral from the Internet.[21] This has resulted in an increase in the number of children who present at an age older than 6 months and many who have had previous unsuccessful nonsurgical treatment elsewhere. This change in patient population has led us to expand the age range of our traditional indications for nonsurgical treatment rather than to default to extensive corrective surgery based solely on older age or previous treatment.

Because of this more recent experience, we are reevaluating the efficacy of the Ponseti method for the correction of congenital idiopathic clubfoot. This study also examined the effect of our changing population in the context of the age of the patients at the onset of treatment and previous treatment.

From the Department of Orthopaedic Surgery, University of Iowa, Iowa City, Iowa.

Received for publication Dec 6, 2002; accepted Jul 7, 2003.

Reprint requests to (J.A.M.) Department of Orthopaedic Surgery, 200 Hawkins Dr, Iowa City, IA 52242. E-mail: jose-morcuende@uiowa.edu

METHODS

Patient Population and Treatment Protocol

We reviewed the records of 157 patients with congenital idiopathic clubfoot (256 clubfeet) who were treated consecutively under the supervision of the senior author from January 1991 to December 2001. Positional clubfeet were not included. Institutional review board approval was obtained. The average age at last follow-up was 26 months (range: 6 months to 8 years). No patient was lost to follow-up.

The guidelines for the treatment developed by the senior author and followed at our institution are as follows[18]: 1) all components of the deformity are corrected simultaneously, not in sequence, except for the equinus, which should be corrected last; 2) the cavus, which results from pronation of the forefoot in relation to the hind foot, is corrected together with the adduction by supinating and abducting the forefoot in proper alignment with the hind foot; 3) with the longitudinal arch of the foot well molded and the forefoot in some supination, the entire foot can be abducted gently and gradually under the talus, which is secured against rotation in the ankle mortise by applying counterpressure with the thumb against the lateral aspect of the head of the talus; 4) heel varus will correct when the entire foot is fully abducted under the talus; the heel is never touched (Fig 1); 5) finally, the equinus is corrected by dorsiflexing the foot; this is generally facilitated by a simple percutaneous tendoachilles tenotomy under local anesthesia.

For maintaining the correction obtained by gentle manipulation, a plaster cast is applied in 2 sections. The first section extends from the toes to just below the knee, and the second covers the knee and the thigh. The knee is immobilized at a right angle. The plaster cast is molded to fit the anatomy precisely. Abduction of the foot is increased progressively with each manipulation and plaster cast application until hypercorrection to ~70° of foot abduction is obtained. All of the casts in all of the patients included in this study were applied under the supervision of the senior author (I.V.P.; Fig 2). Radiographs are taken in the rare case of a deformity that resists correction to rule out any bony abnormality. If full, initial correction is not achievable, then surgical treatment is indicated. The surgical procedure is tailored to the residual deformity. No severity classification is used because the deformity is not necessarily related to the resistance to correction. However, we used the number of casts required to obtain a full correction of the deformity as a proxy for severity of the deformity.

Fig 1. Manipulation as described by Ponseti. The thumb is positioned over the lateral aspect of the head of the talus, and the index finger is positioned behind the lateral malleolus. No counterpressure should be applied at the calcaneocuboid joint. The cavus and the adduction are corrected by slight supination and abduction of the forefoot. The forefoot is never pronated.

After correction, a foot-abduction brace is used to maintain the correction. This brace consists of a bar with shoes attached at the ends at 70° of outward rotation on the affected side and 40° on the normal side. The length of the bar should be equal to the width of the child's shoulders (Fig 3). The brace is used on a full-time basis for 2 to 3 months and at night and during naptime for 3 to 4 years. Parent self-report on brace wear was used to assess compliance. Noncompliance was defined when the foot abduction brace was not used for at least 10 hours a day.

A relapse is defined as the appearance of any of the components of the deformity, including cavus, adductus, varus, and/or equinus. Relapses after initial correction are treated with additional manipulation and serial casting in marked foot abduction. A tendoachilles tenotomy is indicated when dorsiflexion of the ankle is <15°. When the anterior tibial muscle tends to strongly supinate the foot during gait, its transfer to the third cuneiform will prevent additional relapses in most patients.

Analysis

We evaluated the following variables: age of the patient at first visit to our institution, previous treatment and type of treatment before referral, number of casts, previous tendoachilles tenotomy, number of casts required at our institution, need for percutaneous tendoachilles tenotomy, degree of ankle dorsiflexion after tenotomy, and compliance with the foot-abduction brace. These variables were in turn related to the need for extensive corrective surgery and the incidence of relapses. Fisher exact tests, *t* tests, and odds ratios were used as appropriate.

RESULTS

A total of 107 (68%) patients were male. Seventy-nine (60%) patients were first-born. Thirty-three (22%) patients had a positive family history of clubfoot deformity. Most children (92%) were full term, without complications during gestation or delivery. At initial Ponseti casting, 128 (81%) patients were younger than 6 months and 29 (19%) were older than 6 months.

A total of 113 (73%) patients had some form of treatment before their initial visit to our institution. Seven (4.5%) had physical therapy, and 111 (71%) had serial manipulation and casting. The number of casts ranged from 1 to 20, with a median of 10. Patients had primarily below-the-knee casts (49%) or a combination of below-the-knee and above-the-knee casts (24%). Fourteen (9%) patients had a percutaneous tendoachilles tenotomy. Ninety-five percent of the patients came to our clinic with all of the components of the deformity uncorrected. Extensive corrective surgery was recommended to 75 (48%) patients by their treating physicians.

Clubfoot correction was obtained in all but 3 (98%) patients. These 3 patients were previously treated in other institutions and presented with very severe deformities. Correction was obtained with 1 to 7 casts; 90% of the patients required ≤5 casts for correction (Fig 4). The average time from the first cast to the tendoachilles tenotomy (full correction of the deformity) was 20 days (range: 14–24 days). Percutaneous tendoachilles tenotomy was performed in 86% of the cases. Average ankle dorsiflexion post-tenotomy was 20° (range: 0–35°). The majority of patients started walking at an age of 13 months (range: 9–17 months). Twelve (8%) patients had a cast complication, including erythema, slight swelling of the toes, or downward slippage of the cast. All these complications were attributed to a deficient casting technique. No infections, skin necrosis, neu-

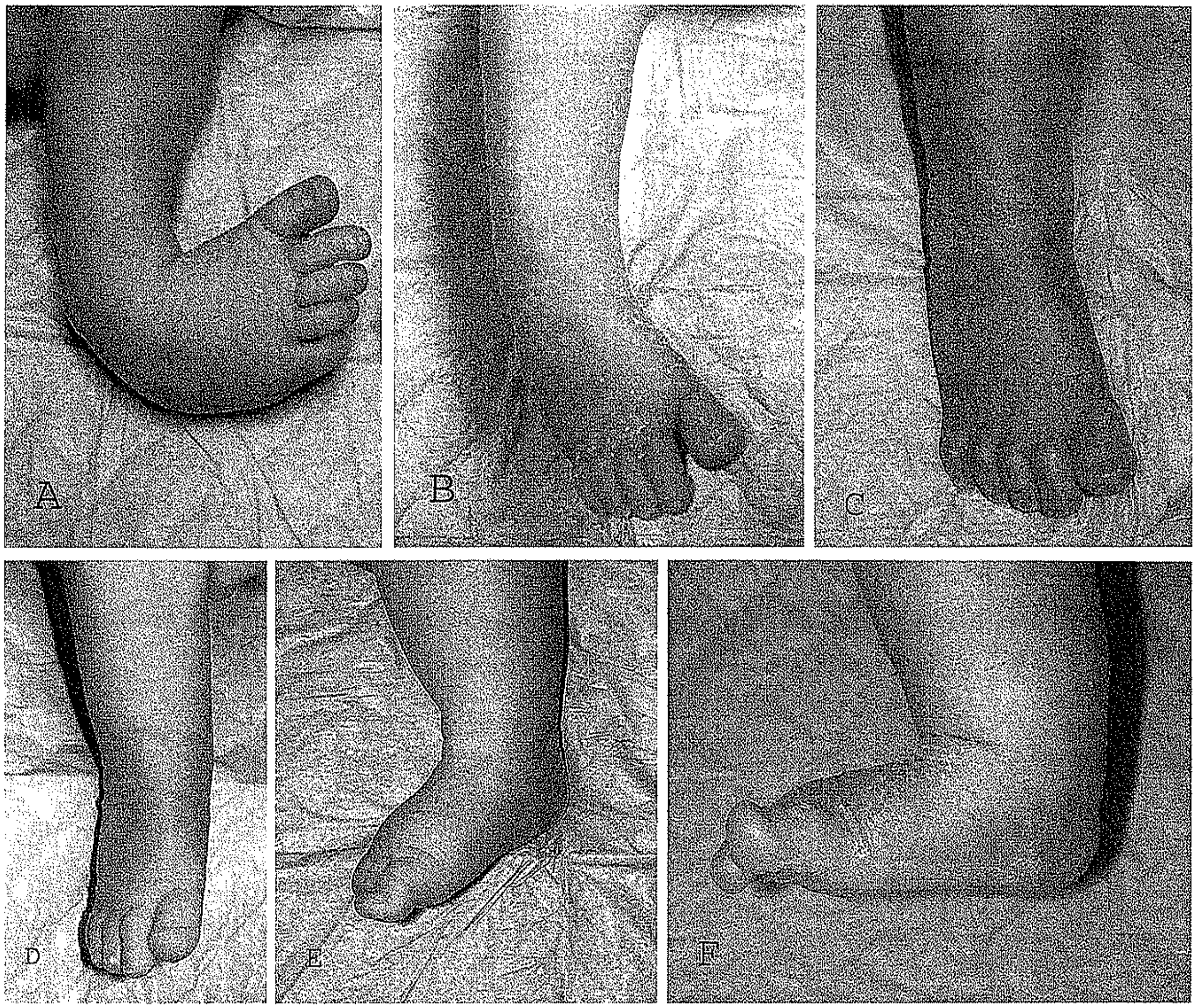


Fig 2. Serial photographs at weekly intervals of the correction of a severe clubfoot deformity in a 3-week-old infant. A, At initial visit. B, After first cast. C, After second cast. D, After third cast. E, After fourth cast. F, Treatment result after percutaneous tendoachilles tenotomy.

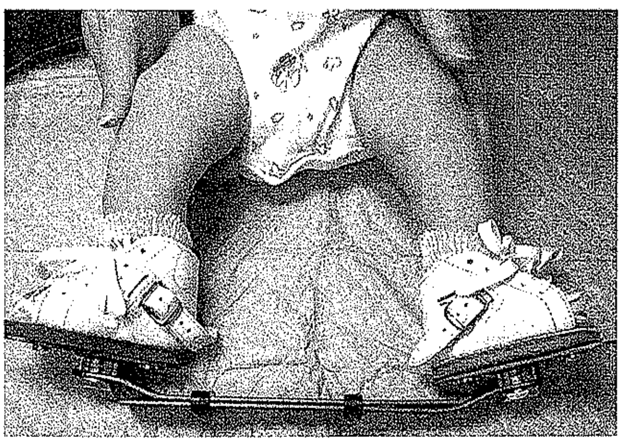


Fig 3. Foot-abduction brace. The brace consists of a bar with shoes attached at the ends at 70° of outward rotation on the affected side and 40° on the normal side. The length of the bar should be equal to the width of the child's shoulders. The brace is used on a full-time basis for 2 to 3 months and at night and during naptime for 3 to 4 years.

rovascular compromise, or profuse bleeding post-tenotomy were observed.

Four (2.5%) patients required extensive corrective surgery after treatment by the Ponseti method. The surgical procedures performed included 1 posteromedial release and 3 posterior releases with tendoachilles tenotomy. It is interesting that of the 75 patients whose deformities were previously indicated for corrective surgery by the local physician, only 1 went on to surgery after treatment by the Ponseti method.

There were 17 (10%) relapses after initial successful treatment. Relapse of the deformity was not significantly related to age at presentation, previous unsuccessful treatment at other institution, or the number of casts required for correction (used as a measure of severity; all $P > .05$). Relapses were associated with noncompliance with the foot-abduction brace ($P = .001$; Table 1). Noncompliance was associated with a 17 times greater odds of relapse (15

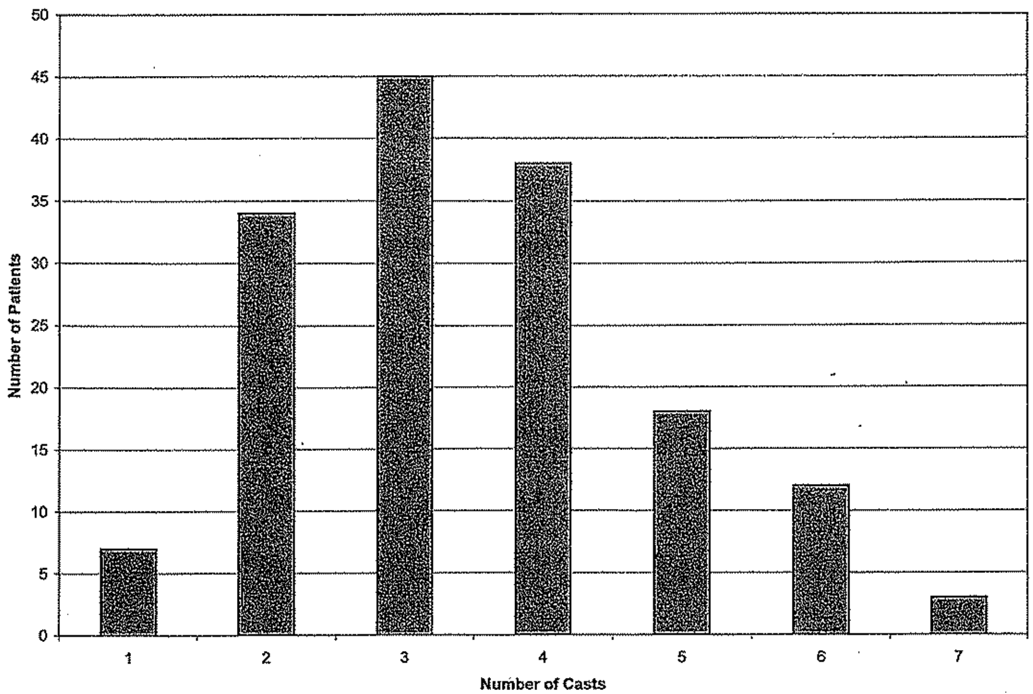


Fig 4. Total number of casts required for full correction of the deformity.

TABLE 1. Factors Associated With Relapse After Full Correction of the Deformity

	P Value
Age of patient	.98
Previous treatment	.5
Number of Ponseti casts	.14
Compliance with orthosis	.001

of 17) compared with compliance (6 of 140; $P = .0001$). Relapses were treated with a second series of manipulation and casting, followed by the use of the foot-abduction brace. Three patients required a second tendoachilles tenotomy. For preventing additional relapses in 4 (2.5%) patients who were noncompliant with the foot-abduction brace, an anterior tibial tendon transfer to the third cuneiform and a tendoachilles lengthening were performed.

DISCUSSION

This study demonstrates that with the use of the Ponseti method, >95% of patients' idiopathic clubfoot can be corrected without the need for extensive corrective surgery. In addition, we found no increased difficulty correcting the deformity in children up to the age of 2 years or in patients who previously had a nonsurgical corrective attempt.

The results of this study are in contrast with most published series.[2–17] We believe that this discrepancy in the results of treatment is attributable primarily to a deficient understanding of the nature of the deformity and the normal functional anatomy of the foot. This lack of understanding has led to poor corrective manipulation and casting techniques. It is not attributable, on the basis of the current study, to the complexity or the severity of the deformity.

The main reason for failures is the application of counterpressure on the calcaneocuboid joint during the manipulation. By so doing, the normal movement of the calcaneus under the talus, a motion that is fundamental for the correction of the deformity, is prevented. Because the 3 tarsal joints move simultaneously, blocking the calcaneocuboid joint in turn prevents the movement of the talonavicular joint and therefore makes it impossible to correct the clubfoot. In addition, many physicians perform these maneuvers somewhat forcefully, often causing the child great distress.[10,22] The correction should be performed very gently to avoid these problems because crying and pain are associated with increased muscle tension in the lower extremity, making the manipulation and casting more difficult.

An important finding in this study was the decreased number of patients who presented with a relapse after initial full correction when compared with our previous publication.[19] We believe that this is attributable to the hyperabduction now obtained in the last cast and to the education of parents about the need to use the foot-abduction brace at night and naptime until the age of 3 years.

Our study has a number of important implications for parents, children, and physicians. From the public health standpoint, our findings can be used to reassure the public that the congenital idiopathic clubfoot deformity, although complex in nature, is easily corrected and, more important, that our results can be replicated in other institutions and clinical practices and even in different health care systems. Herzenberg et al[23] recently reported similar good results in their institutions. They evaluated 27 patients (34 clubfeet) after serial manipulation and casting following the Ponseti method. Control subjects included patients who were treated with initial serial short-leg casts for 3 months (range: 2–6 months).

Only 1 (3%) clubfoot that was treated by the Ponseti method required extensive corrective surgery compared with 32 (94%) in the control group. In addition, a significant decrease in the range of motion in patients who were treated surgically was found compared with those who were treated by the Ponseti method.

Pirani et al[24,25] introduced the Ponseti method in Uganda in November 1999 and developed a national program for the treatment of clubfoot. As in many other developing countries, many, if not most, children who are born with clubfoot do not receive any treatment of the deformity. Through training of physicians and other health care personnel and public awareness campaigns, >80% of the patients have their deformity completely corrected within 2 months of onset of treatment. The numbers of infants who are younger than 1 year and being referred for extensive corrective surgery has reduced remarkably. The success of this program is such that it has already been expanded to Malawi, Tanzania, and Ethiopia (S. Pirani, J. N. Penny, and M. Steenbeeck, personal communication, 2002).

In conclusion, the Ponseti method is a very safe, efficient treatment for the correction of clubfoot that radically decreases the need for extensive corrective surgery. Furthermore, it can be used successfully in children up to ~2 years of age when no previous surgical treatment has been attempted. The decline in extensive clubfoot surgery should encourage national efforts to make this method the gold standard in the treatment of congenital idiopathic clubfoot. Educational programs should be targeted to primary care physicians to increase awareness of the Ponseti method and its excellent results so that they can advise families accordingly. Physicians who adopt the Ponseti method will feel rewarded by the satisfaction of successfully correcting what traditionally has been a very frustrating deformity to treat.

REFERENCES

1. Ventura SJ, Martin, JA, Curtin, SC, Mathews TJ. Report of final natality statistics, 1996. *Mon Vital Stat Rep.* 1998;46(suppl):1–99
2. Kite JH. Nonoperative treatment of congenital clubfoot. *Clin Orthop.* 1972;84:29–38
3. Dimeglio A, Bonnet F, Mazeau PH, De Rosa V. Orthopaedic treatment and passive motion machine: consequences for the surgical treatment of clubfoot. *J Pediatr Orthop B.* 1996;5:173–180
4. Dewaele J, Zachee B, De Vleeschauwer P, Fabry G. Treatment of idiopathic clubfoot: critical evaluation of different types of treatment programs. *J Pediatr Orthop.* 1994;3:89–95
5. Turco VJ. Resistant congenital clubfoot: one-stage posteromedial release with internal fixation: a follow-up report of a fifteen-year experience. *J Bone Joint Surg Am.* 1979;61:805–814
6. Crawford AH, Marxen JL, Osterfeld DI. The Cincinnati incision: a comprehensive approach for surgical procedures of the foot and ankle in childhood. *J Bone Joint Surg Am.* 1982;64:1355–1358
7. Simons GW. Complete subtalar release in clubfeet. I: a preliminary report. *J Bone Joint Surg Am.* 1985;67:1044–1055
8. Green ADL, Lloyd-Roberts GC. The results of early posterior release in resistant club feet. A long-term review. *J Bone Joint Surg Br.* 1985;67:588
9. Aronson J, Puskarich CL. Deformity and disability from treated clubfoot. *J Pediatr Orthop.* 1990;10:109–112
10. Crawford AH, Gupta AK. Clubfoot controversies: complications and causes for failure. *Instr Course Lect.* 1991;45:339–346
11. Atar D, Lehman WB, Grant AD. Complications in clubfoot surgery. *Orthop Rev.* 1991;20:233–239
12. Vizkelety T, Szepesi K. Reoperation in treatment of clubfoot. *J Pediatr Orthop.* 1989;9:144–147
13. Tarraf YN, Carroll NC. Analysis of the components of residual deformity in clubfeet presenting for reoperation. *J Pediatr Orthop.* 1992;12: 207–216
14. Krauspe R, Vispo Seara JL, Lohr JF. Long-term results after surgery for congenital clubfoot. *Foot Ankle Surg.* 1996;2:77–82
15. Sobel E, Giorgini RJ, Michel R, Cohen SL. The natural history and longitudinal study of the surgically corrected clubfoot. *J Foot Ankle Surg.* 2000;5:305–320
16. Uglow MG, Clarke NM. Relapse in staged surgery for congenital talipes equinovarus. *J Bone Joint Surg Br.* 2000;82:739–743
17. Bradish CF, Noor S. The Ilizarov method in the management of relapsed club feet. *J Bone Joint Surg Br.* 2000;82:387–391
18. Ponseti IV. *Congenital Clubfoot: Fundamentals of Treatment.* Oxford, England: Oxford University Press; 1996
19. Ponseti IV, Smoley EN. Congenital clubfoot: the results of treatment. *J Bone Joint Surg Am.* 1963;45:261–275
20. Cooper DM, Dietz FR. Treatment of idiopathic clubfoot. A thirty-year follow- up. *J Bone Joint Surg Am.* 1995;77:1477–1489
21. Morcuende JA, Egbert M, Ponseti IV. The effect of the Internet in the treatment of congenital idiopathic clubfoot. *Iowa Orthop J.* 2003;23:83–86
22. Grayev AM, Boal DK, Wallach DM, Segal LS. Metaphyseal fractures mimicking abuse during treatment for clubfoot. *Pediatr Radiol.* 2001;31: 559–563
23. Herzenberg JE, Radler C, Bor N. Ponseti versus traditional methods of casting for idiopathic clubfoot. *J Pediatr Orthop.* 2002;22:517–521
24. Pirani S. The Ponseti method and results in developing nations. Presented at the Symposium on Conservative Methods on the Treatment of Clubfeet. SICOT. August 30, 2002; San Diego, CA
25. Penny JN, Steenbeeck M. Community based rehabilitation (CBR) in the management of clubfoot deformity in Africa. Third International Clubfoot Congress, August 27–28, 2002; San Diego, CA

A method for the early evaluation of the Ponseti (Iowa) technique for the treatment of idiopathic clubfoot

Wallace B. Lehman, Ahamed Mohaideen, Sanjeev Madan, David M. Scher, Harold J. P. Van Bosse, Michelle Iannacone, Jamal S. Bazzi and David S. Feldman

The Ponseti casting technique is reported to have a high success rate in the treatment of idiopathic clubfoot. Non-operative treatment of clubfoot provides a lower complication rate, less pain, and higher function as the patient ages than operative treatment. To demonstrate serial post-treatment change in clubfeet over time, three clubfoot rating systems were utilized in the current study. Patients compliant with the Ponseti technique and treated before the age of 7 months, had a 92% success rate at an early follow-up after casting was completed. It is not the purpose of this article to analyze the long-term clubfoot treatment result but to establish tools which can be used to judge initial success with the Ponseti technique. Complications are few and minor, limited to equipment used and cast technique. *J Pediatr Orthop B* **12:133–140 © 2003 Lippincott Williams & Wilkins.**

Journal of Pediatric Orthopaedics B 2003, 12:133–140

Keywords: Ponseti, Kite, Dimeglio/Bensahel, foot-abduction orthosis

Pediatric Orthopaedic Surgery, New York University Hospital for Joint Diseases, New York, New York, USA.

Correspondence and requests for reprints to Wallace B. Lehman MD, Chief, Emeritus, Department of Pediatric Orthopaedic Surgery, NYU-Hospital for Joint Diseases, 301 E. 17th Street, New York, NY 10003, USA.
Tel: +1 212 598 6403; fax: +1 212 598 6084;
e-mail: wallace.lehman@med.nyu.edu

Introduction

Historically, treatment of clubfoot is challenging. Lloyd-Roberts wrote in 1964, 'clubfoot will doubtless continue to challenge the skill and ingenuity of orthopaedic surgeons, but so long as much fundamental knowledge eludes us, our practice will continue to be flavored with a certain ingenious empiricism. Art has had its day. Let us now resolve to concentrate on the science of orthopaedic surgery' [1].

The prevalence of clubfoot has been reported in the orthopaedic literature to be two per 1000 births [2], with the definitive treatment being largely surgical. The majority of all clubfeet in reported series end in surgical releases, primarily in patients between the ages of 3 months and 1 year, despite early serial casting [2].

The most common surgical procedure is a soft tissue release of those structures that create the deforming forces in the clubfoot. The primary disadvantages of soft tissue release in the young clubfoot patient are a high complication rate and, when complications do occur, they are difficult to treat. The most common complications are recurrence of the deformity, with an average rate of 25% (13–50% range) [2–4]. Other complications include infection, neurovascular injury, loss of limb and over-correction [2]. It is to avoid the high recurrence rate previously perceived by the authors following soft tissue clubfoot release and the difficult revision procedures necessary for salvage that the Ponseti method was considered and tested statistically.

The serial casting technique most often cited was described by Kite [5]. His reported success was greater than 90%. However, consistent reproducibility of this rate has not been noted in many studies. Ponseti described another fundamentally different casting technique, which is coming under greater scrutiny after being initiated at the University of Iowa in 1950 [6,7]. However, the techniques, as described by Ponseti and Kite, have not been analyzed by any statistical means. Our purpose was to describe the early results of the Ponseti (Iowa) casting technique in a center specifically designed to serially monitor the outcomes with previously established rating methods.

Method

As part of our clubfoot center, care is taken to exactly duplicate the Ponseti technique.

Description of the Ponseti casting technique

A brief description of the Ponseti casting technique is provided here. For a more detailed description, the reader is referred to the published works of Ignacio V. Ponseti MD [8–10].

While both Kite's and Ponseti's techniques analyze the deformity of the clubfoot in terms of its component parts,

DOI: 10.1097/01.bpb.0000049579.53117.4a

there is a distinctly different approach to each part. Both state the components to include the midfoot adductus, cavus, and hindfoot varus and equinus; however, Kite's technique attempts to correct the deformity using the calcaneocuboid joint as the fulcrum point [2]. Ponseti's technique, on the other hand, centers around the talonavicular joint and, unlike the Kite method, there is no direct manipulation of the calcaneus out of its varus position [2,3,6,10]. The Ponseti technique utilizes five basic cast types, each of which has specific purposes in the treatment scheme [8,10]. The actual number of casts used on a foot vary in accordance with the response to each subsequent cast.

The first cast attempts to correct the relative pronation of the first metatarsal and cavus by maximally supinating the foot but without dorsiflexion. This correction is achieved by bringing the first metatarsal in line with the varus of the hindfoot which is, by Ponseti's description, pronated in relation to the other metatarsals. While the first cast is quite counterintuitive, the second, third, and fourth casts use sequentially increasing amounts of abduction to achieve the maximal amount of correction prior to addressing the hindfoot equinus. At no point during the casting is there direct manipulation of the calcaneus. Instead, Ponseti's theory is that the calcaneus moves out of its varus position during the manipulation.

After correction of the adductus, cavus and hindfoot varus, if there is easy, passive dorsiflexion of the foot to 15° above neutral, a final cast is placed on for 3 weeks in a dorsiflexed position. If this passive dorsiflexion is not possible with the examiner using the pressure of one finger, a percutaneous release of the Achilles tendon is performed, and the final cast is placed for 3 weeks. After the 3-week time period, the feet are placed in a foot abduction orthosis modified with a 15° bend to maintain the correction achieved. The foot abduction orthosis is worn full time for 3 months or until the child is cruising, whichever event occurs first. Afterwards, the bar is kept in place only at night until the child is 3–4 years of age.

Description of the clubfoot clinic protocol

The purpose of the clubfoot center, established in December 1999, at the Hospital for Joint Diseases, was to scientifically detail our results with the Ponseti casting technique. A pediatrician evaluated each patient enrolled in the clubfoot center, and a detailed birth history was obtained. Any prior casting treatment was also noted. Prior to initiation of treatment, parental instruction and teaching was performed. All patients had their first casts placed on their first visit.

To chart progress or decline during the course of treatment of each patient, three described clubfoot rating methods were utilized: (1) a modified Dimeglio/Bensahel [11] method, (2) the Catterall/Pirani [12,13], and (3) a modification of the functional rating developed at the Hospital for Joint Diseases [3]. The Dimeglio/Bensahel classification incorporated eight components: equinus, varus, position of the talo-calcaneal-forefoot unit, forefoot adduction, and the presence of abnormal musculature, cavus, a medial crease, and a posterior crease. A total of 20 points was possible, the higher the number, the more rigid the clubfoot (Fig. 1).

The Catterall/Pirani method utilized by our clinic was the most recent version; it incorporated six components rather than the originally described 10. These items were the position of the lateral border of the foot, amount of medial and posterior creasing, the emptiness of the heel, degree of palpation of the lateral head of the talus, and the extent of ankle dorsiflexion passively. Again, similar to the Dimeglio/Bensahel scoring, the higher the score, the more rigid was the clubfoot, with six being the highest possible sum (Fig. 2). The Hospital for Joint Diseases Functional Rating involved a maximum score of 60 (best), with six components being rated. These were ankle dorsiflexion and heel position with maximum passive manipulation, quantity of subtalar motion, the forefoot appearance, the amount of medial creasing, and the quantity of cavus (Fig. 3).

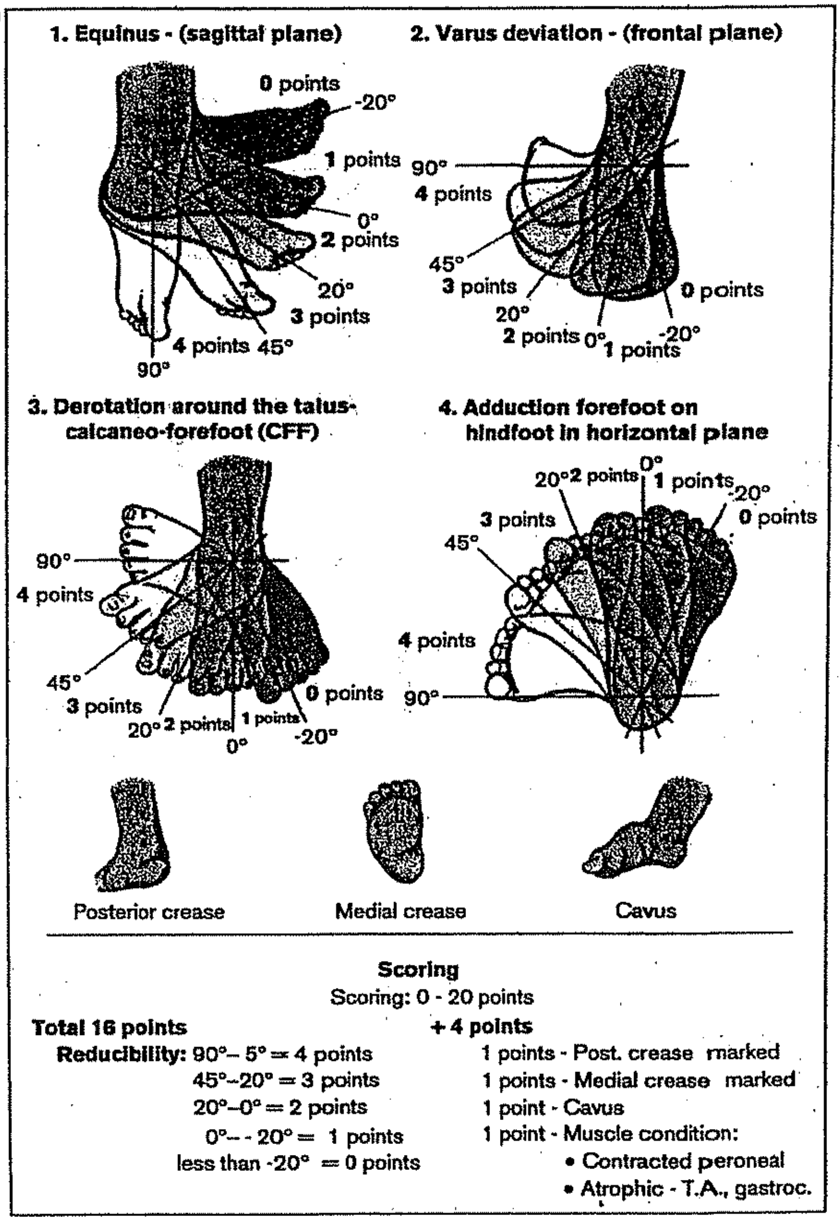
It was hoped that consistency between the methods would note trends during the treatment of each clubfoot. For ease of recording of our data, a single sheet was created to contain all relevant information. Posters of each rating system were placed in each examining room to minimize variation in scoring (Fig. 4). To maintain all data in a succinct manner in our records, derotation of the talo-calcaneo-forefoot in the Dimeglio/ Bensahel rating system was characterized as supination/pronation but with the same scoring.

All individuals involved in casting and rating were instructed in the rating methodology. All castings were performed by or under the direct supervision of either pediatric orthopaedic attendings or pediatric orthopaedic fellows to allow for consistency in the casting and rating. At each visit to the clinic, all feet were rated prior to each casting or tenotomy and prior to placement in foot abduction orthoses.

After casting was completed, the rating of feet continued during the foot abduction orthosis stage of the treatment. Along with the rating of the feet, other details were noted, including if the patient had a percutaneous Achilles tenotomy, complications with treatment, and compliance with the treatment plan. These factors were regularly monitored at each visit to the clinic (Fig. 4).

Fig. 1

(a)



(b)

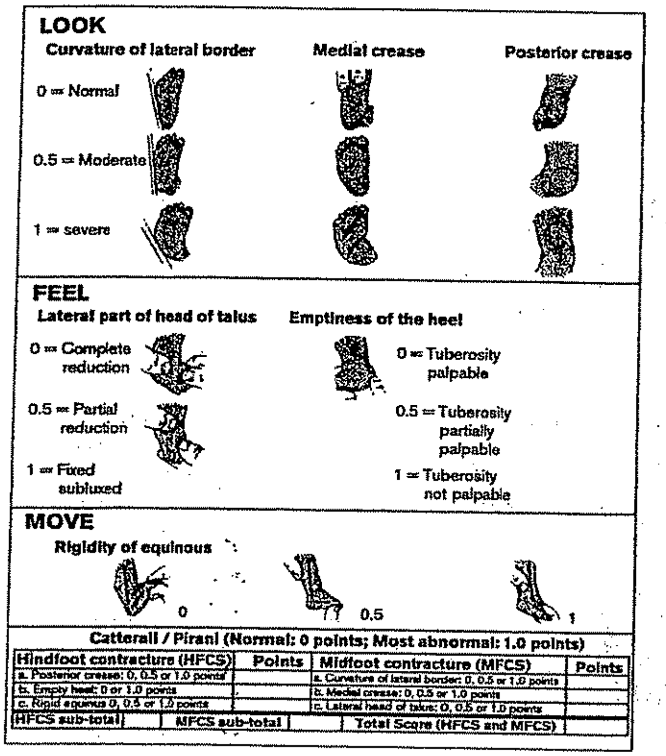
Type I	Benign 20% of all club feet *Soft – soft feet* 0 – 5 points > 90° reducible Postural clubfeet
Type IIa	Moderate feet 33% of all club feet *Soft – Stiff* 6 – 10 points Partially reducible
Type IIb	Severe feet 35% of all club feet *Stiff – Soft* 11 – 15 points More resistant than reducible
Type III	Very severe 12% of all club feet *Stiff – stiff* 16 – 20 points Irreducible

(a) The modified Dimeglio/Bensahel method [5]. (b) The modified Dimeglio/Bensahel shown as type I, type IIa, type IIb, and type III [5].

Selection of patients and data collection

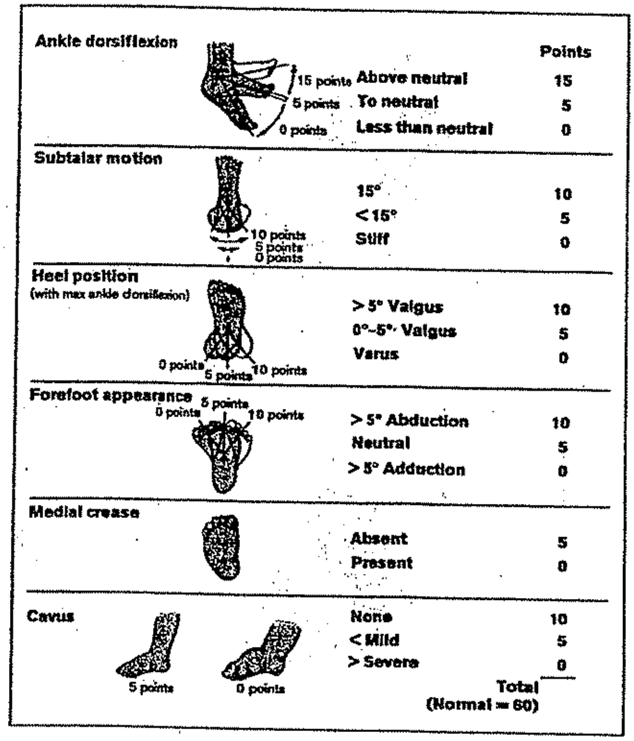
Since inception of the clubfoot center at the Hospital for Joint Diseases 63 patients (87 feet) have been treated. Those patients selected for inclusion in our study group numbered 30 patients, a total of 45 clubfeet, with 15 patients having bilateral clubfoot. The first 30 patients with 45 clubfeet followed for 3 months form the substance of this review. None of these patients were lost to follow-up. Inclusion criteria included patients casted by the Ponseti technique with a minimum of 3 months follow-up after the last cast applied. All patients had idiopathic clubfoot. Clubfeet secondary to syndromic involvement were excluded. Data collected for each patient included sex, right or left foot, age at treatment onset, total number of casts placed, ratings of feet at each clubfoot center visit, and pretreatment radiograph, which was not used in our treatment scheme.

Fig. 2



The modified Catterall/Pirani scoring [10].

Fig. 3



The modified Hospital for Joint Diseases functional rating system [1].

Results

Patients were divided into two groups. Group I included all patients using foot abduction orthoses, while group II involved those who were not placed into a foot abduction orthosis because of failure with casting. Group I numbered 40 feet, while group II numbered five feet.

The mean age of presentation for all patients was 10.8 weeks (range 0.5–40 weeks). Group I and group II had mean ages at presentation of 8.2 weeks (range 0.5–28 weeks) and 34 weeks (26–40 weeks), respectively. However, the median for group I was 4 weeks of age and 36 weeks of age for group II.

The total number of castings per foot averaged 5.4 (range 4–9) for the entire study group. Group I averaged 5.3 castings (range 4–9), while Group II averaged 6.4 (range 4–9). The number of castings performed varied with each patient. When all components of the clubfoot other than equinus were corrected, the foot was placed into the last cast, either with or without percutaneous tenotomy.

The number of percutaneous tenotomies, after only one series of castings, numbered 25 while three patients had open Achilles tendon lengthening and posterior releases done intraoperatively. Two of these feet had previous percutaneous tenotomies performed. The open Achilles tendon and posterior releases were done to analyze under image intensification the effectiveness of the release in our first cases. This is not done now and is not part of the Ponseti technique.

Utilizing the Wilcoxon signed ranks test, there was a significant difference between the initial and last follow-up scores using all three scoring systems in group I (40 feet). As seen in Table 1, the Dimeglio/Bensahel score changed from a mean of 14.4 to 4.2 while the Catterall/Pirani decreased from 4.6 to 0.6. The functional rating was shown to increase from 16.8 to 52.9. All three had P values of below 0.0001 (Table 1).

Patients were labeled as having a good result if two of three criteria were met: (1) Dimeglio/Bensahel 6 points or better (Fig. 1); (2) Catterall/Pirani 1.5 points or better (Fig. 2); (3) functional rating greater than 30 (Fig. 3). Thirty-eight feet had good results prior to application of the foot abduction orthosis. There were two feet in group I that had poor results after casting and were indicated for open Achilles tendon lengthening/

Fig. 4

Name____________________________________ **Foot (circle): R L**

Cast Number (circle): 0 1 2 3 4 5 6 7 8 9 Date DBB Applied Compliance: 1) YES 2) NO

Complications (circle) 0)None 1)Rocker sole 2)MAceration 3)Abrasion 4)Blister 5)Slough 6)Decubitus 7)Cast saw injury 8)Cast intolerance/removal)Other

Surgical Date: Procedure: (circle) 1)None 2)Per-Q Achilles tenotomy 3)Open TAL/post release 4)PMR 5)Anterior tibialis transfer 6)Other ________

Dimeglio/Bensahel

1.Equinus	Points	3. Midfoot Rotation (horizental place)	Points	For Parts 5-8, Mark Points as Present =1, Absent =0	Points
Plantarflexion 45° - 90°	4	Supination 45° - 90°	4		
Plantarflexion 20° - 45°	3	Supination 20° - 45°	3	5. Posterior crease	
Plantarflexion 0° - 20°	2	Supination 0° - 20°	2	6. Medial crease	
Dorsiflexion 20° - 0°	1	Pronation 20° - 0°	1	7. Cavus	
Dorsiflexion > 20°	0	Pronation > 20°	0	8. Abnormal underlying musculature	
2. Hindfoot varus		**4. Forefoot Adduction (on hindfoot)**			
Varus 45° - 90°	4	Adductus 45° - 90°	4	TOTAL SCORE/TYPE	
Varus 20° - 45°	3	Adductus 20° - 45°	3	Type I: 0 - 5 points	
Varus 0° - 20°	2	Adductus 0° - 20°	2	Type IIa: 6 - 10 points	
Valgus 20° - 0°	1	Adductus 20° - 0°	1	Type IIb: 11 - 15 points	
Valgus > 20°	0	Adductus > 20°	0	Type III: 16 - 20 points	

Functional Rating (circle corresponding point valuation, add up total)

1. Ankle Dorsiflexion	Points	3. Heel Position (with man ankle) dorsiflexion)	Points	5. Medial Crease	Points
Above neutral	15	> 5° Valgus	10	Absent	5
To neutral (+/- 5°)	5	0° - 5° Valgus	5	Present	0
Less then neutral	0	Varus	0	**6. Cavus**	
2. Subtalar Motion		**4. Forefoot Appearance**		None	10
15°	10	> 5° Abduction	10	< 5 millimeters	5
15°	5	Neutral	5	> 5 millimeters	0
Suff	0	> 5° Abduction	0	**Total (of 60)**	

Catteral/Pirani (Normal; 0 points; m,ost abnormal 1.0 points)

Hindfoot contracture (HFCS)	Points	Midfoot contracture (MFCS)	Points
a. Posterior crease: 0.0.5. or 1.0 points		a. Curvature of lateral border: 0.0.5 or 1.0	
b. Empty heel: 0.0.5 or 1.0 points		b. Medical crease: 0.05 or 1.0 points	
c. Rigid equinus: 0.0.5 or 1.0 points		c. Lateral head of talus: 0. 0.5. or 1.0 points	
HFCS Sub-total		MFCS Sub-total / Total Score (HFCS and MFCS)	

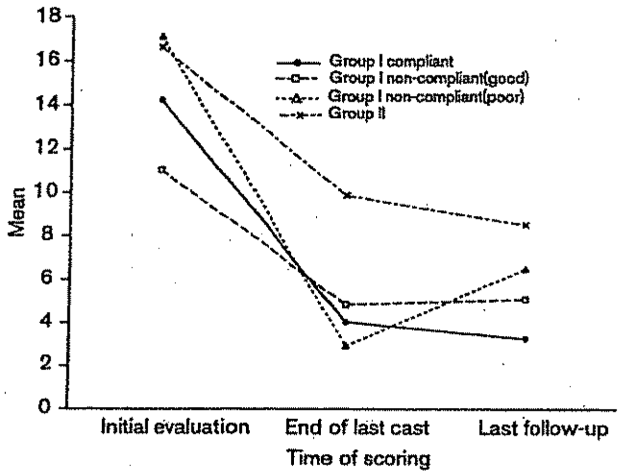
Data sheet for the clubfoot clinic with all pertinent data to be collected for each visit.

posterior release. These two feet had good results at 3 months follow-up.

The thirty-eight feet placed into Foot Abduction Orthoses were divided based on their compliance with the orthosis. Twenty-seven feet were compliant with orthosis wear. Of the compliant patients, all 27 feet had good results at 3 months follow-up. Of the patients compliant with foot abduction orthosis wear and with good initial results after casting, all maintained their correction at last follow-up (Table 2). We have followed 15 of the 27 feet to a follow-up of 6 months with good results; 10 feet were followed to 9 months and two feet were followed to 12 months.

Despite noncompliance with foot abduction orthosis wear, five of the 11 feet in the non-compliant patients had good results. Three of the six feet with poor results were recast, but two of the feet were lost to follow-up. The remaining foot had a good result at 6 months following the second casting session. One of the six feet had a second casting session and an open Achilles tendon lengthening and posterior release with a good result at 6 months follow-up. Two of the six feet with a poor result

Fig. 5



Group I compliant, group I non-compliant (with good result), group I non-compliant (with poor result) and group II plotted against modified Dimeglio/Bensahel score initially, after casting and at last follow-up.

Table 1 Comparison of initial evaluation and last follow-up scores for entire group I ($n=40$ feet)

	Initial evaluation		Last follow-up		
Scoring system	Mean	SD	Mean	SD	P-value*
Dimeglio/ Bensahel	14.4	3.0	4.2	2.8	<0.0001 (significant)
Functional rating	16.8	10.8	52.9	8.7	<0.0001 (significant)
Catterall/ Pirani	4.6	1.2	0.6	0.6	<0.0001 (significant)

*Wilcoxon signed ranks test.

Table 2 Comparison of initial evaluation and last follow-up scores for group I patients compliant with foot abduction orthosis ($n=27$ feet)

	Initial evaluation		Last follow-up		
Scoring system	Mean	SD	Mean	SD	P-value*
Dimeglio/ Bensahel	14.2	2.8	3.2	2.6	<0.0001 (significant)
Functional rating	18.7	11.0	55.6	7.0	<0.0001 (significant)
Catterall/ Pirani	4.5	1.4	0.4	0.4	<0.0001 (significant)

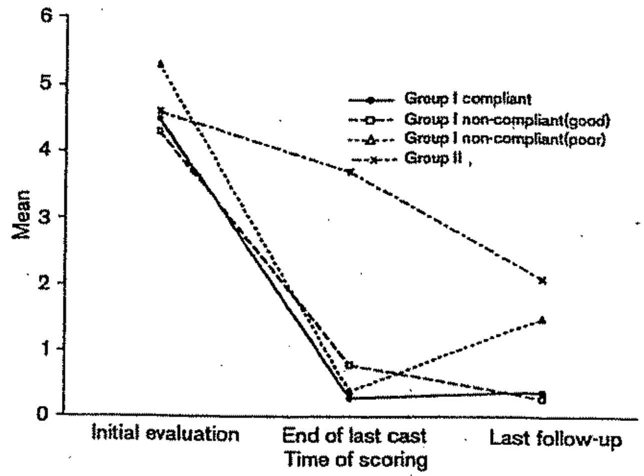
Scores for group I compliant patients only. *Wilcoxon signed ranks test.

had a second casting session with percutaneous Achilles tenotomy. One of these feet had a tenotomy previously while the other did not. Both had good results at 6 months follow-up. The versatility of this technique is that even an unacceptable result can be salvaged by recasting and further tenotomy.

Table 3 Dimeglio/Bensahel types for group I ($n=40$ feet)

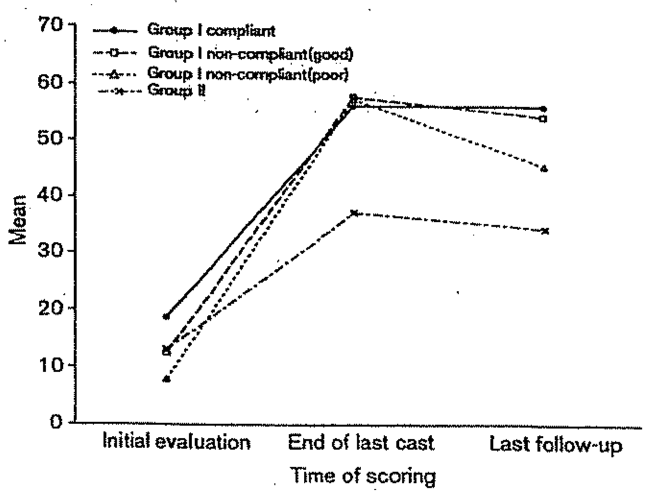
Type	Initial evaluation	End of last cast	Last follow-up
I	0	35 (87.5%)	29 (72.5%)
IIa	7 (17.5%)	5 (12.5%)	11 (27.5%)
IIb	19 (47.5%)	0	0
III	14 (35.0%)	0	0

Fig. 6



Group I compliant, group I non-compliant (with good result), group I non-compliant (with poor result) and group II plotted against Catterall/ Pirani score initially, after casting and at last follow-up.

Fig. 7



Group I compliant, group I non-compliant (with good result), group I non-compliant (with poor result) and group II plotted against Hospital for Joint Diseases functional rating score initially, after casting and at last follow-up.

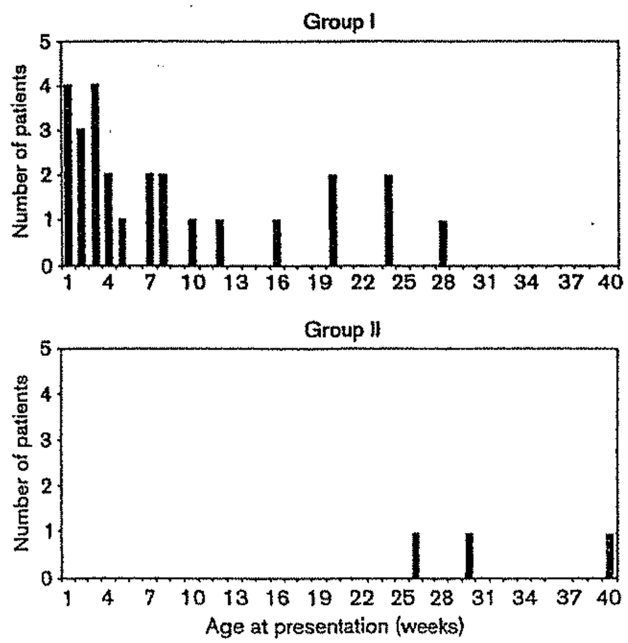
Five feet were in group II with all five patients eventually being recommended for open Achilles tendon lengthening/posterior release because of failure with Ponseti casting. This was despite the larger number of casts placed in this group (average 6.4, range 4–9). All of these patients were over 7 months of age when treated.

Figures 5, 6, and 7 show the Dimeglio/Bensahel, Catterall/Pirani, and Hospital for Joint Diseases scoring systems by group I (compliant and non-compliant with foot abduction orthosis) and group II. While all group I patients showed improvement, those non-compliant with foot abduction orthosis wear had a worsening of their outcomes at last follow-up. Rather than use the initial classification to predict outcome, our results so far have shown that no matter how severe the initial classification is if the technique is done properly a good result can be anticipated.

The age of the patient at initiation of treatment was much higher in group II patients than in group I patients. The average age of group I patients was 8.2 weeks (range 0.5–28 weeks) while the group II patients averaged 34 weeks of age (range 26–40 weeks) (Fig. 8).

When the group I feet (40 feet) were divided by Dimeglio types (I, IIa, IIb, III), a significant shift in classification was shown. While 19 feet were noted to be IIb and 14 feet were type III at initial evaluation, there were no type IIb or III feet at last follow-up (Table 3). There were 11 IIa feet when the entire group I was analyzed. However, when only patients compliant with foot abduction orthoses (27 feet) were noted, only four patients were IIa (Table 4).

Fig. 8



Age distribution for group I and group II.

Table 4 **Dimeglio/Bensahel types for group I patients compliant with foot abduction orthosis ($n=27$ feet)**

Type	Initial evaluation	End of last cast	Last follow-up
I	0	25 (92.6%)	23 (85.2%)
IIa	5 (18.5%)	2 (7.4%)	4 (14.8%)
IIb	14 (51.9%)	0	0
III	8 (29.6%)	0	0

Table 5 **Complications list**

Complication	Quantity
Cast saw injury	7
Abrasions	6
Cast intolerance/removal	5
Maceration	4
Blister	2
Slough	1

There were 25 complications among all the castings performed. This led to a 10.2% complication rate. Nearly 25% of all complications were cast saw injuries (seven total). By switching to the cast knife technique described by Ponseti, these injuries were eliminated (Table 5). Macerations and abrasions occurred more often in the early months of the opening of the clubfoot center. Some patients with marked equinus had casts fall off secondary to the shape of the infant's extremity.

Discussion

The current philosophy on the treatment of clubfoot initially involves a course of serial casting with surgical intervention at age 3–12 months if correction of the components of the clubfoot are not achieved [2]. Most authors have felt that stiff, rigid clubfeet such as Dimeglio type IIb or III, are not amenable to casting alone and that surgical intervention will eventually be warranted. However, the complication rate of clubfoot surgery has been reported to be between 11 and 33% [3,4].

The advantages of a reproducible, easily followed casting method with a high success rate are, therefore, obvious. The casting technique introduced by Ponseti has had a high success rate with Ponseti reporting a success rate of over 90% with anecdotal or descriptive follow-up of 30 plus years [14]. However, there have been no other reports with such high success using his methods in the current literature, but we anticipate more frequent positive reports will be forthcoming [6,15]. In addition, there is currently no literature using existing clubfoot rating methods to evaluate progress with the Iowa casting technique.

Our clubfoot center sought to systematically and exactly reproduce the Ponseti technique in its entirety. To serially follow the progress of the clubfeet treated in our clinic, feet were rated with two described classification systems and a third system that was developed at our institution [11–13].

When our results were analyzed in terms of age, there was a definite correlation with success of the casting technique. In particular, patients treated over the age of 7 months appear to have an increased probability of poor results. Compliance with the foot abduction orthosis has also been an issue. Those patients compliant with foot abduction orthosis wear had nearly 100% success at last follow-up if treatment was applied before the child was 7 months of age. Patients not compliant with foot abduction orthosis wear but, with good results after casting, still had good results in 50% of the feet. The Ponseti technique is flexible in that it provides an opportunity to recast patients who lose correction. Poor outcomes were salvaged by recasting or by recasting with tenotomy.

Our longest follow-up to date has been 12 months. However, the majority of our patients fall into the 3–6 month follow-up period. Ponseti's long-term outcomes, as noted by Cooper and Dietz, have higher function, less pain, and slightly less stiffness in these feet than in those with more extensive surgical procedures [14]. As Ponseti has indicated, some patients may require tibialis anterior tendon transfers to compensate for possible muscle imbalance, resulting in some deformity recurrence. This limited procedure may be required in the future in some of our patients, however, long-term follow-up will determine this. Based on our current data, the Ponseti (Iowa) casting technique provides excellent early results and may limit the necessity of extensive surgical procedures at early ages. Similar statistical evaluation of other techniques, such as early motion and physical therapy may show similar early success, but that was not the purpose of our paper. We anticipate our long-term results to be similar and also to correspond to the short-term data we report here.

Acknowledgements

The authors would like to thank Debra Sala, PT, MS for her invaluable assistance throughout this entire project.

References

1 Lloyd-Roberts GC. Congenital clubfoot [editorials and annotations]. *J Bone Joint Surg Br* 1964; 46B:369–371.
2 Lehman WB. *The clubfoot*. New York: J.B. Lippincott; 1980.
3 Atar D, Lehman WB, Grant AD, Strongwater AM. Revision surgery in clubfeet. *Clin Orthop* 1992; 283:223–230.
4 Viskelety T, Szepesi L. Reoperation in treatment of clubfoot. *J Pediatr Orthop* 1989; 9:144–147.
5 Kite JH. *The clubfoot*. New York: Grune & Stratton; 1964.
6 Herzenberg JA. The Baltimore experience with the Iowa (Ponseti) Technique. Hospital for Joint Diseases Clubfoot Workshop; 25 April 2001; New York.
7 Ponseti IV, Smoley EN. Congenital clubfoot: the results of treatment. *J Bone Joint Surg Am* 1963; 45A:261–275.
8 Ponseti IV. Treatment of congenital clubfoot. *J Bone Joint Surg Am* 1992; 74A:448–454.
9 Ponseti IV. Current concepts: common errors in the treatment of congenital clubfoot. *Int Orthop* 1997; 21:137–141.
10 Ponseti IV. *Congenital clubfoot: fundamentals of treatment*. Oxford: Medical Publications; 1996.
11 Dimeglio A, Bensahel H, Souchet P, Mazeau P, Bonnet F. Classification of clubfoot. *J Pediatr Orthop B* 1995; 4:129–136.
12 Catterall A. A method of assessment of the clubfoot deformity. *Clin Orthop Mar* 1991; 264:48–53.
13 Pirani S. A method of assessing the virgin clubfoot. Pediatric Orthopaedic Society of North America; May 1995; Orlando.
14 Cooper DM, Dietz FR. Treatment of idiopathic clubfoot. A thirty year follow-up. *J Bone Joint Surg Am* 1995; 77A:1477–1489.
15 Pirani S. The Vancouver, and East Africa experience with the Iowa (Ponseti) technique. Hospital for Joint Diseases Clubfoot Workshop; 25 April 2001; New York.

Evaluation of the Treatment of Idiopathic Clubfoot by Using the Ponseti Method

Michael Colburn, DPM,[1] and Matthew Williams, DPM[2]

The initial treatment of congenital idiopathic talipes equinovarus (clubfoot) is most often nonsurgical. However, surgical treatment in the form of posteromedial release is often undertaken after failure of conservative measures. The prevalence of both immediate and long-term complications in surgically treated clubfeet has cultivated a renewed interest in nonsurgical treatment. The Ponseti method for treating clubfoot has seen a revived interest among those caring for infantile clubfeet. We report on our first 34 infants (57 clubfeet) treated by using the techniques and principles described by Ponseti. Using a standard scoring system, 54 of 57 clubfeet were successfully corrected without requiring posteromedial release. Only 2 patients (3 clubfeet) required extensive surgical correction. There were 6 relapses. In all recurrent cases, there was a lack of compliance with the straight-last shoe and foot abduction bar regimen. Based on this level of initial success, we believe that posteromedial release is no longer necessary for the majority of cases of congenital clubfeet. (The Journal of Foot & Ankle Surgery 42(5): 259–267, 2003)

Key words: clubfoot, Ponseti, casting, surgery, talipes equino varus

Congenital idiopathic talipes equinovarus, or clubfoot deformity, is used to describe a complex deformity that occurs in otherwise generally healthy infants. It consists of 4 components: equinus, varus, adductus, and cavus (1–4). It is generally agreed that the initial treatment should be nonsurgical and start as soon as possible after birth (5–10). A variety of manipulations, splinting, strapping, bracing, and casting techniques have been advocated in an attempt to achieve correction of the deformity (5,7,8,11–16). Although some success with nonsurgical treatment has been reported in the literature, results have often been less than optimal, with partial corrections, recurrence, and other complications (6,17–20). This has led to a trend toward surgical intervention, usually within the first year of life (10,13,15,21,22). However, surgical treatment also carries significant risks, and the potential for complications is great. Although generally well tolerated into late adolescence and early adulthood, many patients with clubfoot treated with surgical correction tend to develop feet that are stiff, painful, and weak (16,23,24).

In 1950, Ignacio Ponseti, MD, at the University of Iowa, developed a method of treating clubfoot by manipulation and casting. The clinical correction achieved by using this method has produced a functional, plantigrade foot without requiring posteromedial release in 85% to 90% of cases (1). The correction achieved is long lasting, with some patients having been followed up into the fourth or fifth decade of life. Until recently, these results have not been duplicated at other institutions (25). The purpose of this study was to relate our experience correcting idiopathic clubfoot deformity by using these principles.

Materials and Methods

The first 34 infants with congenital idiopathic clubfeet (57 clubfeet) treated at our institution by using the techniques and principles described by Ponseti were evaluated. Twenty-eight were boys and 6 were girls. Twenty-three infants had bilateral clubfeet, and 11 had unilateral clubfeet. Patients were either referred from the maternity unit of the hospital or from other centers, usually after other treatment regimens with little or incomplete correction.

There were no patients with any congenital syndrome or neuromuscular condition other than clubfoot. Infants were evaluated and graded for severity by using the Dimeglio scale (Table 1) (26). Grading was performed to establish the severity of the deformity before treatment. In this system, 4 parameters are considered to be important: equinus deviation in the sagittal plane, varus deviation in the frontal plane, derotation of the calcaneo-forefoot block in the hor-

From the Department of Orthopedics and Podiatry, San Francisco Bay Area Foot and Ankle Residency, Kaiser Permanente Medical Center, Walnut Creek, CA. Address correspondence to: Matthew Williams, DPM, 1425 South Main St, Walnut Creek, CA 94596. E-mail: matthew.e.williams@kp.org

[1]Diplomate, American Board of Podiatric Surgery; Residency Director, Podiatric Surgical Residency.

[2]Associate, American College of Foot and Ankle Surgeons.

1067-2516/03/4205-0003$30.00/0

doi:10.1053/S1067-2516(03)00312-0

TABLE 1 Dimeglio classification of clubfoot

Essential parameters: the examiner applies a gentle corrective force and records	
Equinus deviation in the sagittal plane (0 to 4 points)	_____
Varus deviation in the frontal plane (0 to 4 points)	_____
Derotation of the calcaneo-forefoot block (0 to 4 points)	_____
Forefoot adduction in the horizontal plane (0 to 4 points)	_____
Further pejorative elements	
Posterior crease (1 point)	_____
Medial crease (1 point)	_____
Cavus (1 point)	_____
Poor muscle condition (1 point)	_____
Overall total score (0 to 20 points)	_____

Scoring: reducibility (equinus, varus, calcaneo-forefoot block derotation, and forefoot adduction)	
90° to 45°	4 points
45° to 20°	3 points
20° to 0°	2 points
0° to −20°	1 point
<−20°	0 points

Grades	Overall total score
Grade 1: Benign feet	0 to 5 points
Grade 2: Moderate feet	5 to 10 points
Grade 3: Severe feet	10 to 15 points
Grade 4: Very severe feet	15 to 20 points

izontal plane (supination), and adduction of the forefoot relative to the hindfoot in the transverse plane. These 4 parameters are assessed for reducibility by applying gentle corrective pressure to the foot. Each parameter is then scored on a 4-point scale: reducibility 90° to 45°, 4 points; 45° to 20°, 3 points; 20° to 0°, 2 points; and 0° to −20°, 1 point. When tested, all 4 parameters can lead to a maximum of 16 points. Four additional elements are also evaluated, and 1 point is added to the score if they are present. These include the presence of a posterior crease, the presence of a medial crease, and the existence of plantar retraction or cavus deformity; 1 point was added for poor muscular condition, such as hypertonic, fibrous or contracted triceps, tibialis anterior, or peroneal tendons (26). Those infants with a reducible clubfootlike deformity at birth were excluded. Each clubfoot was evaluated by 1 of the authors at initial presentation (M.C.), and scored using the strict criteria described by Dimeglio (26). Chart review was used to determine the number and timing of treatments. Patients were evaluated every 3 to 6 months after completion of the initial treatment until 2 years of age to encourage parental compliance with the straight last shoes and foot abduction bar and to evaluate maintenance of the correction. The minimum follow-up for patients included in this study was 1 year.

Criteria for successful outcome were defined as ankle-joint dorsiflexion of >10°, and a plantigrade foot without heel varus. A plantigrade foot was defined as one with the rearfoot and forefoot (all 5 metatarsal heads) in contact with the ground in stance. Heel varus was defined as any degree of inversion of the calcaneus compared with the long axis of the tibia in stance. Charts were then reviewed at the time of data collection, with specific attention given to each of the criteria. The ultimate assignment of a successful outcome was determined by the senior author at the time of final evaluation.

Treatment Protocol

Patients were treated as soon as possible after birth. The course of treatment followed the principles of manipulation and casting described by Ponseti (1). Initial treatment consisted of gentle stretching and mobilization, followed by application of well-molded, thinly padded plaster casts that were changed every 5 to 7 days.

The first session of mobilization and casting was intended to correct the cavus and some adduction of the forefoot. The cavus is a result of pronation of the forefoot on the rearfoot and is primarily a plantarflexion of the first metatarsal. To correct the cavus, the forefoot is gently supinated and abducted by applying pressure from plantar-medial to dorsal-

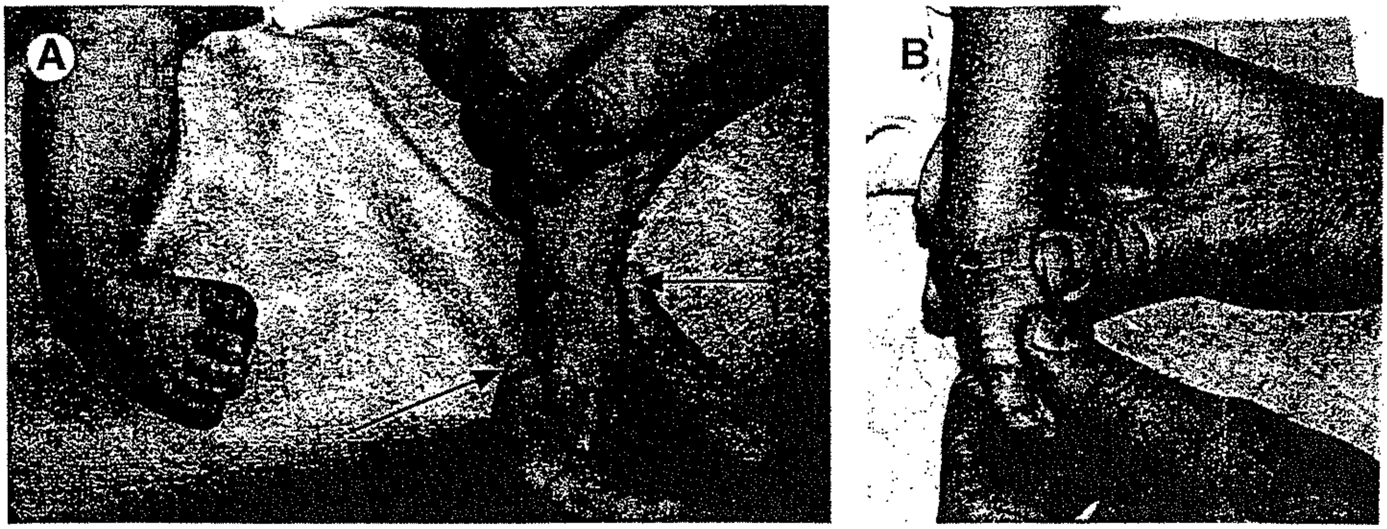


FIGURE 1 (*A*) One-handed manipulation technique and (*B*) 2-hand manipulation technique. Note that the thumb is placed over the palpable head of the talus laterally and not over the calcaneocuboid joint. The arrows show the points where pressure is applied. The foot distal to the talus is supinated to correct the forefoot cavus and is then abducted to allow the anterior portion of the calcaneus to rotate laterally and correct the heel varus.

lateral on the first metatarsal head. The talus is firmly prevented from rotation in the ankle mortise with counterpressure from the practitioner's thumb placed on the easily palpable lateral aspect of the talar head. This may be accomplished with either a 1-handed or a 2-handed manipulation technique (Fig. 1). This allows for external rotation of the foot under and distal to the talus. The cavus deformity of the forefoot usually corrected after 1 or 2 treatments. Correction of the cavus deformity places the metatarsals, cuneiforms, cuboid, and navicular onto the same plane, forming the lever arm required to laterally mobilize the navicular, cuboid, and calcaneus. This will be accomplished as the tight medial soft-tissue structures (ligaments, tendons, and joint capsule) gradually yield to gentle, persistent manipulation.

In subsequent casting sessions, the foot was gently manipulated and mobilized before cast application. A well-molded cast was then applied as described previously, with the foot held in the corrected position until the plaster hardened. The patient returned in 5 to 7 days and the casts were removed. The mobilizations and casting were continued at each visit, with simultaneous correction of the cavus, adduction deformity, and heel varus.

Heel varus was corrected by abduction of the foot distal to the talus, which allowed lateral rotation of the navicular, cuboid, and anterior aspect of the calcaneus. The subtalar, talonavicular, and calcaneocuboid joints function with mechanical interdependence, and rotate around a moving, rather than a fixed, axis (27–29). Abduction of the foot distal to the talus allows the heel to come out of its supinated position where it was previously locked into varus under the talus (29,30). The heel must never be forcibly everted while the calcaneus is locked under the talus because this will cause a breach in the midfoot and result in a bean-shaped foot (1). During mobilization and casting, the talus must be fixed in the ankle mortise by firm pressure on the lateral aspect of the talar head while the foot under the talus is abducted. Importantly, the calcaneus must never be touched because lateral pressure against the calcaneus or calcaneocuboid joint prevents lateral rotation of the calcaneus and correction of the heel varus. Ponseti referred to this as "Kite's error" (1,31,32).

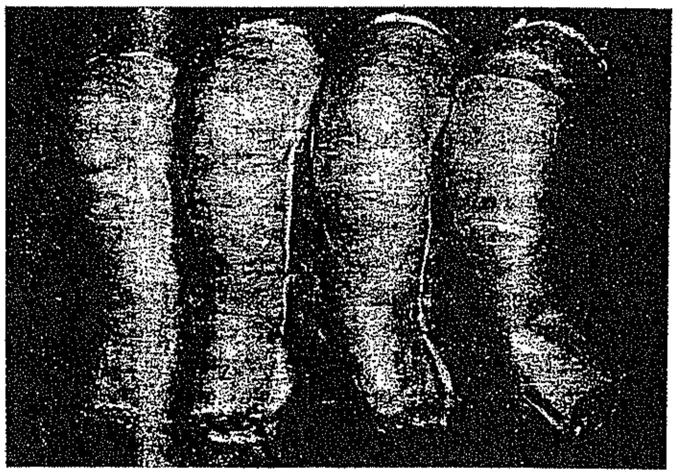


FIGURE 2 Series of 4 consecutive clubfoot casts from the same patient, showing correction of all deformities (except equinus), with the foot abducted on the talus 50° to 60° by the fourth casting. The casts were applied weekly.

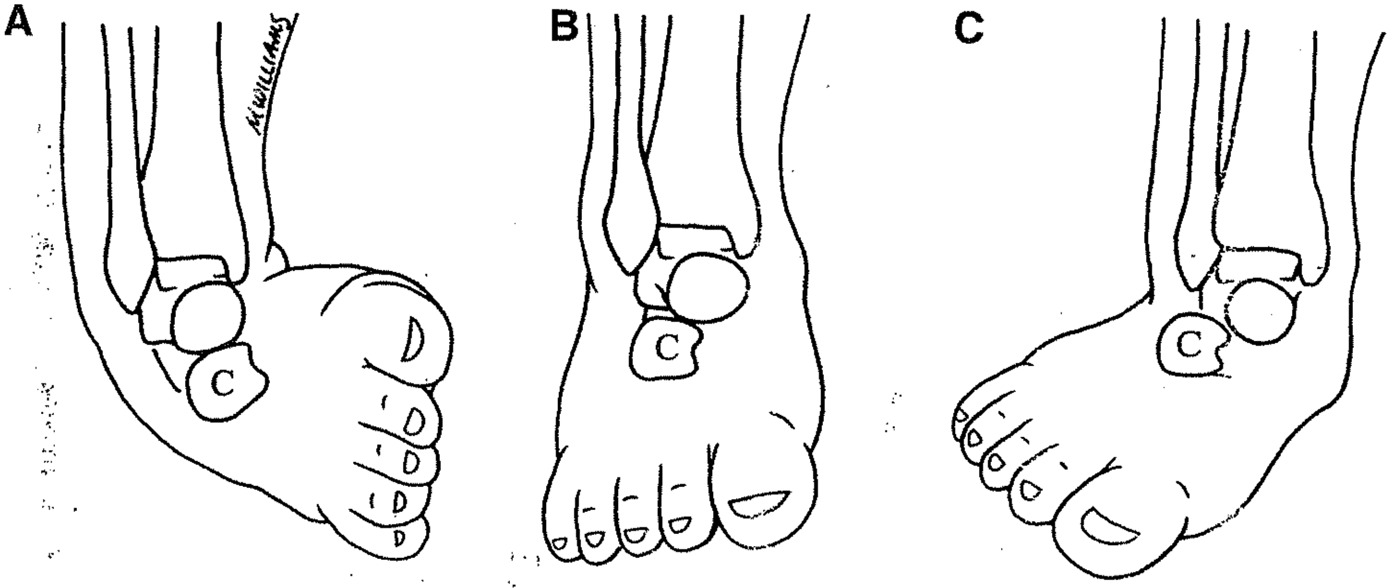


FIGURE 3 (A) The anterior portion of the calcaneus (C) is beneath the head of the talus in clubfoot. (B) As the foot is abducted under the talus, the anterior portion of the calcaneus moves laterally. (C) The foot is abducted under the talus 50° to 60°. This allows the anterior portion of the calcaneus to abduct out from under the head of the talus to allow dorsiflexion of the anterior portion of the calcaneus and correction of the equinus deformity.

The equinus was not addressed until all other deformities were corrected (usually after 3 or 4 visits) and the foot was able to be abducted 50° to 60° on the talus (Fig. 2). Once the anterior portion of the calcaneus had rotated laterally about the interosseous talocalcaneal ligament, dorsiflexion of the anterior calcaneus may occur (Fig. 3). When full abduction of the foot on the talus was achieved, the equinus was corrected by percutaneous Achilles tenotomy or by casting. Abduction of the foot under the talus allows the anterior portion of the calcaneus to rotate out laterally from under the talar head and neck where it was prevented from dorsiflexing. If tenotomy is attempted before 50° to 60° of abduction of the foot is achieved, inadequate correction of the equinus will result.

The Achilles tenotomy may be performed in an operating room or in a clinic setting. Local anesthetic cream was applied under occlusion for 30 minutes and then local anesthetic was injected. The foot and leg were given a sterile preparation and the tenotomy was performed through a single small posteromedial incision. A sterile dressing was applied and the ankle joint dorsiflexed and placed in a cast in the corrected position for 3 weeks.

After completion of the casting regimen, the feet were placed in straight-last shoes with a foot abduction bar, with the feet externally rotated 60° to 70°. The bar was worn 23 hours per day for 3 months. Time in the foot abduction bar is then gradually decreased to a minimum of 12 hours per day until the child is 2 years old.

Results

The age at initial presentation ranged from 1 day to [illegible] months. Average follow-up was 23 months (range, 12 to [illegible] months). The average Demeglio score for virgin clubfeet (no previous treatment) was 11.2 (range, 7 to 15). The average score for clubfeet that received previous treatment (non-Ponseti) was also 11.2 (range, 7 to 17).

Thirty-two of 34 patients and 54 of 57 (95%) clubfeet were corrected without requiring posteromedial release (Fig 4). Sixty-seven percent of clubfeet (38 clubfeet) were corrected with serial manipulations and casting and with Achilles tenotomy. Twenty-eight percent (16 clubfeet) were corrected with manipulation and casting alone, and 5% clubfeet) required posteromedial release. Detailed information regarding treatment and outcomes may be found in Tables 2 and 3.

All clubfeet (24 clubfeet) in which the index method was the first and only treatment regimen were corrected without a posteromedial release. The average number of casts required for correction was 4.8 (range, 3 to 7). In infants in whom the Ponseti method of treatment began after other treatment attempts, 30 of 33 clubfeet were corrected without posteromedial release. All of these infants had manipulation and castings (non-Ponseti) at our institution or at other institutions without correction. Several of these infants had been scheduled for surgical correction, which was then

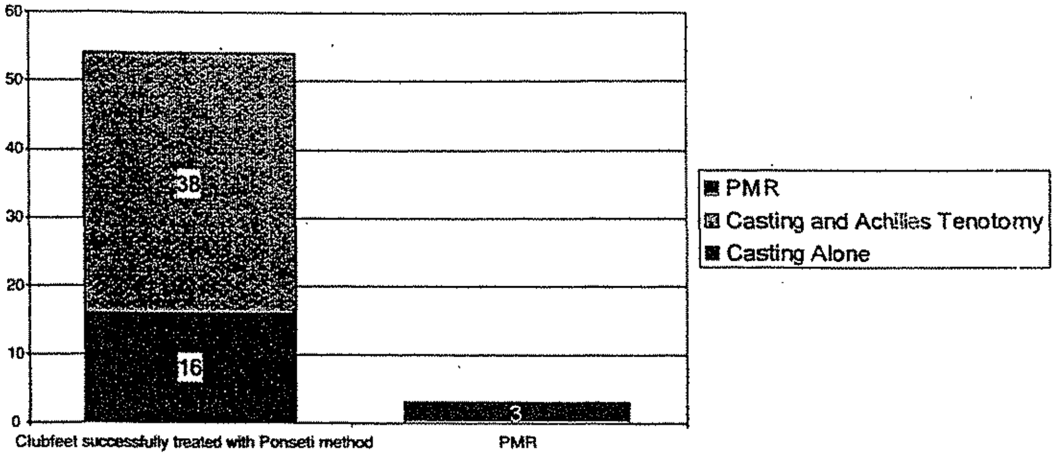


FIGURE 4 Number of clubfeet corrected by using the Ponseti method or by surgical correction with full posteromedial release. PMR, posteromedial release.

TABLE 2 Clubfeet with no previous teatment before treatment with the Ponseti method (n = 24)

Patient	Sex	Treated Side	Age at Treatment Onset (days)	Dimeglio Score, Right Foot	Dimeglio Score, Left Foot	No. of Casts Required for Correction	No. Corrected With Casting and Achilles Tenotomy	No. Corrected With Casting Alone	Clubfeet Requiring Posteromedial Release Surgery	Length of Follow-up (mos)	Recurrence Requiring Retreatment
1	F	R	3	7	—	3	0	1	0	32	0
2	M	L	12	—	13	4	1	0	0	30	0
3	M	L	12	—	11	5	1	0	0	29	1
4	M	B	4	10	10	5	2	0	0	25	0
5	M	B	1	15	15	6	2	0	0	28	0
6	M	B	5	11	11	5	2	0	0	23	1
7	M	B	1	12	12	5	2	0	0	26	1
8	M	B	11	12	12	7	2	0	0	21	0
9	F	L	7	—	11	5	1	0	0	21	0
10	M	B	38	12	12	6	2	0	0	20	1
11	M	B	12	10	10	5	2	0	0	20	0
12	M	B	12	11	11	4	2	0	0	17	0
13	M	B	5	10	10	4	2	0	0	17	0
14	M	B	6	10	10	3	0	2	0	12	0
			Average	Average		Average	Total	Total	Total	Average	Total
n = 24			9.2	11.2		4.8	21	3	0	22.9	4

Abbreviations: B, bilateral; F, female; L, left; M, male; R, right.

canceled after successful completion of this treatment protocol. The average number of casts required for correction in these patients was also 4.8 (range, 3 to 14). Summary results of the number of casts required for correction in all patients are shown in Figure 5. Six patients suffered a relapse despite initial successful correction. However, in all 6 cases, the parents admitted to noncompliance with the straight-last shoe and foot abduction bar regimen. Serial mobilization and casting was again performed, with correction again achieved, and the straight-last shoe with foot abduction bar regimen was reinstituted in each of these patients. Correction was successfully maintained with parental compliance and none of these infants required surgical intervention.

Discussion

The method of serial manipulations and casting developed and mastered by Ignacio Ponseti, MD, at the University of Iowa in 1950 was instituted and applied to infants with congenital clubfoot deformity in an effort to achieve a plantigrade, functional foot without resorting to surgical intervention (1,33). The long-term outcome of this tech-

TABLE 3 Clubfeet that recieved non-Ponseti treatment before treatment with the Ponseti method (n = 33)

Patient	Sex	Treated Side	Age at Treatment Onset (days)	Dimeglio Score, Right Foot	Dimeglio Score, Left Foot	No. of Casts Required for Correction	No. Corrected With Casting and Achilles Tenotomy	No. Corrected With Casting Alone	Clubfeet Requiring Posteromedial Release Surgery	Length of Follow-up (mos)	Recurrence Requiring Retreatment
1	M	B	56	9	9	5	2	0	0	36	0
2	F	R	49	8	—	5	1	0	0	36	0
3	M	R	111	12	—	5	1	0	0	36	0
4	M	R	130	9	—	4	1	0	0	33	0
5	M	B	135	11	11	5	2	0	0	30	0
6	M	B	114	11	11	4	2	0	0	28	0
7	F	B	177	11	11	4	2	0	0	28	0
8	F	B	112	9	9	3	0	2	0	26	0
9	M	L	121	—	11	6	1	0	0	22	0
10	M	B	104	12	12	3	0	2	0	20	0
11	M	L	30	—	11	4	1	0	0	20	0
12	M	B	33	7	7	3	0	2	0	20	0
13	M	B	130	17	17	6	0	0	2	19	0
14	M	L	39	—	6	3	0	1	0	18	0
15	F	B	292	15	15	6	2	0	0	19	1
16	M	R	194	15	—	14	0	0	1	20	0
17	M	B	54	12	12	5	0	2	0	14	1
18	M	B	155	11	11	3	0	2	0	16	0
19	M	B	33	11	11	3	0	2	0	12	0
20	M	B	13	13	13	5	2	0	0	14	0
			Average	Average		Average	Total	Total	Total	Average	Total
n = 33			104.1	11.2		4.8	17	13	3	23.4	2

Abbreviations: B, bilateral; F, female; L, left; M, male; R, right.

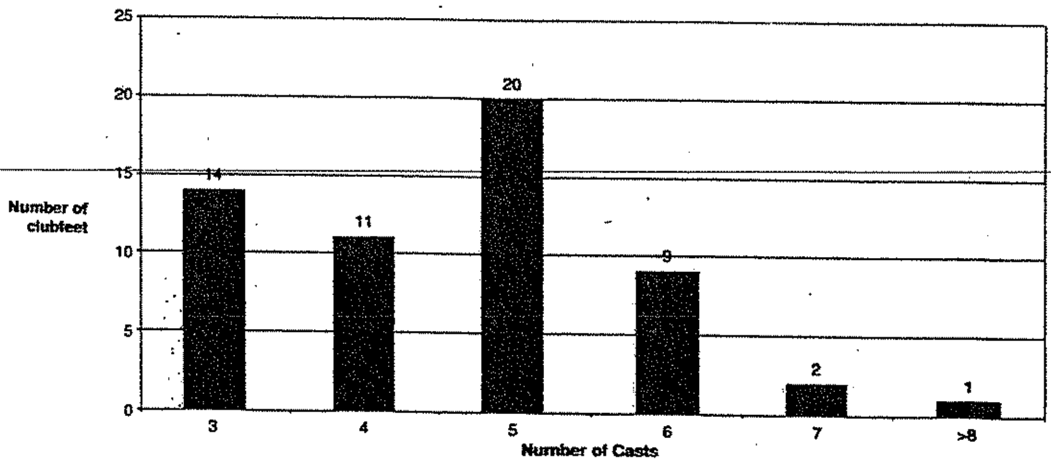


FIGURE 5 Number of casts required for correction.

nique has been reported to result in satisfactory functional results in 85% to 90% of feet when appropriately applied (34–36). Nonsurgical treatment regimens of manipulation and casting at other institutions have had less success and have been associated with such complications as increased cavus deformity, false correction with midtarsal breach and rocker-bottom deformity, flattening of the talar dome, pressure sores from casts, and even fractures secondary to excessive force during manipulation (6,19,20,37).

Since the early 1970s, this has led to a trend tow[illegible] surgical intervention in cases of congenital clubfoot, [illegible]marily in the form of the posterior and medial soft-ti[illegible] releases as described by Turco (15), with modification[illegible] Crawford et al (21), and McKay (3,13,38). Surgery is [illegible]ally performed at 6 months to 1 year of age. Exten[illegible] surgical release carries both immediate and long-term [illegible]herent risks. Wound complications including scarring, [illegible]fection, neurovascular compromise, and avascular necr[illegible]

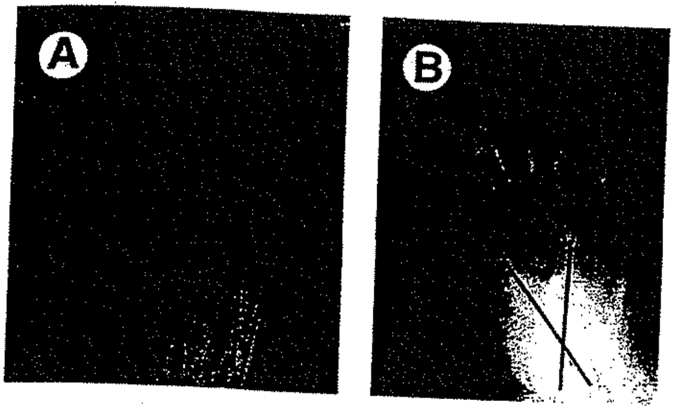


FIGURE 6 Dorsoplantar radiographs of congenital clubfoot (*A*) before and (*B*) after correction by using the Ponseti method, showing correction of the talocalcaneal angle.

may occur in the immediate postoperative setting (39, 40). Overcorrection with calcaneus deformity, heel valgus, pes planus, and forefoot abduction, and undercorrection with persistent equinus, heel varus, and metatarsus adductus may also occur (38,41–43). Because these complications have become more readily evident, a renewed interest in nonsurgical treatment of congenital clubfoot has occurred.

Ponseti (44) has reported a relapse rate of 78% in patients noncompliant with the straight-last shoe and abduction bar regimen and a relapse rate of 7% in compliant patients. All of the noncompliant patients in Ponseti's (44) series were corrected with recasting). In all 6 relapses in this study, the parents admitted to noncompliance with the straight-last shoe and foot abduction bar regimen. Although there remains some controversy in the literature, we speculate that the tendency to relapse may be caused by the intrinsic contractile nature of the soft tissues in clubfoot deformity, as postulated by Ponseti (1) and others (45,46). Although the number of patients in this study is small, our results and those of Ponseti suggests that the importance of maintaining correction with the foot abduction bar is paramount to successful treatment.

This renewed interest has focused attention on the Ponseti method because of the previously reported high rates of success (6,30,34,36). We have found that this treatment protocol leads to reliable restoration of the clubfoot deformity to a functional, plantigrade foot in 95% of our patient series. This is supported by both the clinical and radiographic appearance of the corrected foot. Radiographs taken before treatment with the Ponseti method and after completion of treatment show correction of the angular relationships of the tarsal bones, consistent with correction of the clubfoot deformity (Fig. 6).

Although radiographs remain the most common method of evaluating the position of the tarsal bones before and after clubfoot treatment, accurately assessing the degree of talonavicular subluxation with plain radiographs is difficult. The navicular is radiographically silent until the age of 3 or older, and there is eccentricity of the ossific nucleus in the talar neck (47). Therefore, the axis drawn through the ossific nucleus of the talus may not accurately represent the axis of the entire bone. Despite these limitations, radiographs continue to be used to assess clubfeet and the results of treatment.

Improvements in imaging techniques, specifically with magnetic resonance imaging have allowed accurate assessment of the degree of talonavicular subluxation in clubfoot and observation of the response to treatment. Pirani (48) showed the effectiveness of the Ponseti method of treatment by using magnetic resonance imagaint to evaluate the positions of the talus and the navicular in clubfeet before, during, and after treatment. Not only did reduction of the talonavicular joint occur but also correction of the abnormal shapes of the tarsal bones occurred (Fig. 7), which was attributed to changes in mechanical loading of fast-growing cartilaginous tissues, similar to that described by Wolff (48,49) in the bone. This further confirms the clinical evidence that we have seen but have been unable to document with radiographs because of the delay in appearance of the navicular ossific nucleus. The apparent remodeling of the abnormal shapes of the tarsal bones documented with magnetic resonance imaging lends further support to the importance of the earliest possible intervention with the Ponseti method. The results of this study also support this because none of the infants treated from birth with the Ponseti method required posteromedial release.

Limitations of this study include the subjective evaluation of examiners, although efforts were made to address this by using a standard scoring system for initial evaluation, and measurable criteria for successful outcome. In children who received non-Ponseti treatment, we are unable to verify precisely what type of casting or treatment they received, and whether this treatment corrected any of their initial deformity or created additional pathology. In this group of patients, the initial severity grade did not necessarily correlate with treatment outcome; however, children at all levels of severity were corrected with the Ponseti method. The relatively small number of patients and short follow-up (average of 23.2 months) is an additional limitation. However, a longer follow-up study will show whether this level of success may be maintained and will provide additional insight into the functional outcomes of clubfeet treated with this method.

Conclusion

Our results show that careful adherence to the treatment protocol and an improved understanding of the pathologic anatomy can result in similar rates of successful outcomes similar to those achieved by Ponseti. The treatment process

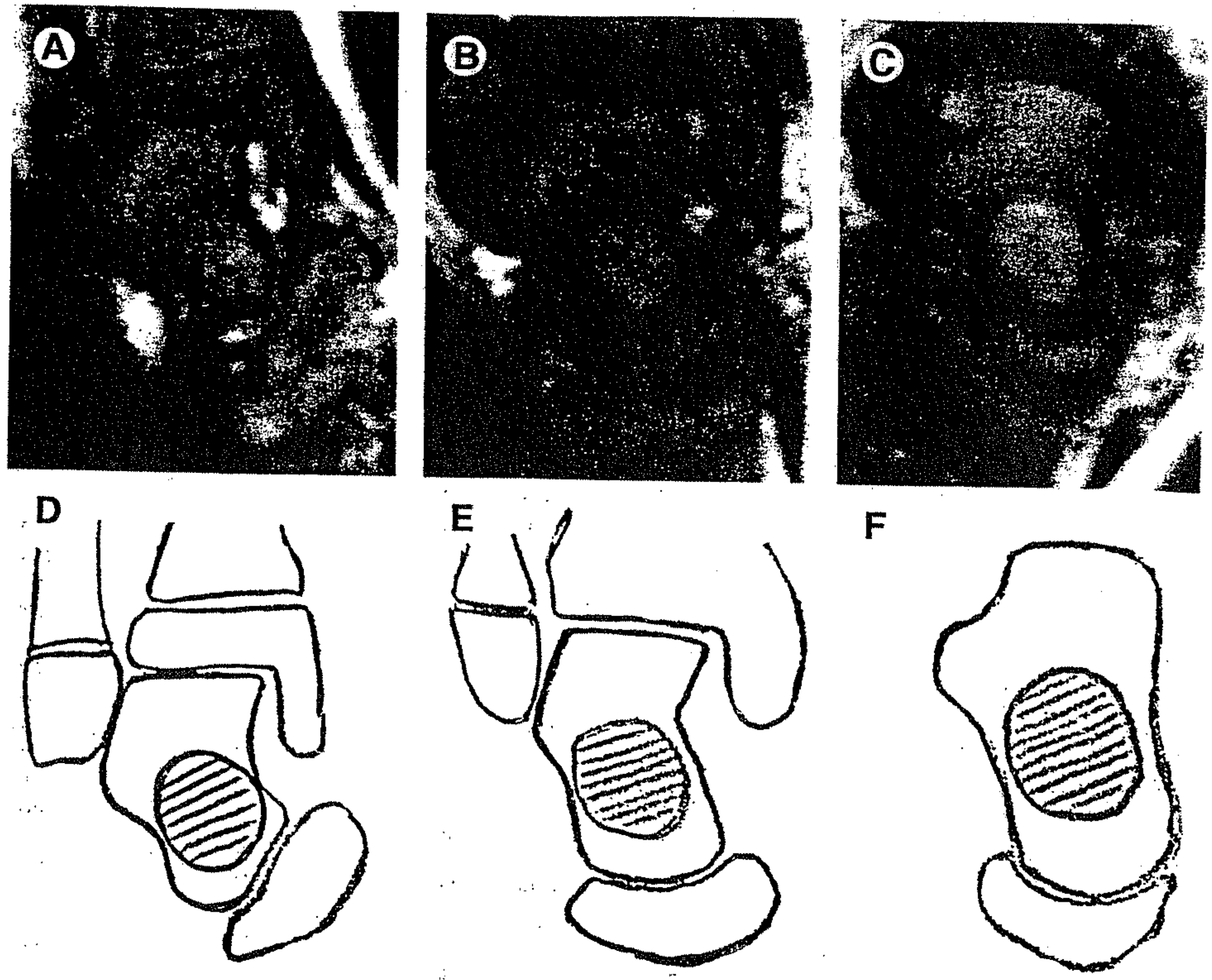


FIGURE 7 Sequential oblique axial magnetic resonance images perpendicular to the talonavicular joint show progressive correction of the medial talar neck inclination, the medial talonavicular displacement, and the wedge-shaped navicular from the (*A*) first cast to the (*B*) third cast to the (*C*) fifth cast applied after percutaneous tenotomy. With the application of the fifth cast, the medial talar neck inclination was reduced to normal and the talonavicular joint was reduced anatomically and congruently. (*D–F*) Tracings of the correction of the medial talar neck inclination and the medial talonavicular displacement. Reprinted with permission (48).

is simple and effective. In the majority of cases, the need for posteromedial release is obviated and potential complications are avoided.

Acknowledgment

The authors thank Stephen Silvani, DPM, and Robert Cooke, DPM, for their contributions to this study.

References

1. Ponseti IV. *Congenital Clubfoot. Fundamentals of treatment.* New York, Oxford University Press, 1996.
2. Simon GW, Sarrafian S. The microsurgical dissection of a stillborn fetal clubfoot. Clin Orthop 173:275, 1983.
3. McKay DW. New concept of and approach to clubfoot treatment: section I—principles and morbid anatomy. J Pediatr Orthop 2:347–356, 1982.
4. Irani RN, Sherman MS. The pathological anatomy of clubfoot. J Bone Joint Surg 45A:45–52, 1963.
5. Kite JH. *The Clubfoot.* Philadelphia, Grune & Stratton, 1964.
6. Ponseti IV, Smoley EN. Congenital clubfoot: the results of treatment. J Bone Joint Surg 45A:261–275, 1963.
7. Ikeda K. Conservative treatment of idiopathic clubfoot. J Pediatr Orthop 12:217–223, 1992.
8. Bensahel H, Guillaume A, Czukonyi Z, Desgrippes Y. Results of physical therapy for idiopathic clubfoot: a long-term follow-up study. J Pediatr Orthop 10:189–192, 1990.
9. DeValentine SJ, Blakeslee TJ. Congenital talipes equinovarus. *In Foot*

and Ankle Disorders in Children, edited by SJ DeValentine. New York, Churchill Livingstone, 1992.
10. Blakeslee TJ. Congenital idiopathic talipes equinovarus (clubfoot). Current concepts Clin Podiatr Med Surg 14:9–56, 1997.
11. Scarpa A. A memoir on the congenital club feet of children, and the mode of correcting that deformity. 1818 Clin Orthop 308:4–7, 1994.
12. Kite JH. Non-operative treatment of congenital clubfoot. Clin Orthop 84:29–38, 1972.
13. McKay DW. New concept of and approach to clubfoot treatment: section II—correction of the clubfoot. J Pediatr Orthop 3:10–21, 1983.
14. Simons GW. *The Clubfoot: The Present and a View of the Future*. New York, Springer-Verlag, 1994.
15. Turco VJ. Surgical correction of the resistant club foot: one-stage posteromedial release with internal fixation. A preliminary report. J Bone Joint Surg 53A:477–497, 1971.
16. Nutt JJ. Diseases and Deformities of the Foot. EB Treat, New York, 1915.
17. Aronson J, Puskarich CL. Deformity and disability from treated clubfoot. J Pediatr Orthop 10:109–119, 1990.
18. Karski T, Wosko I. Experience in the conservative treatment of congenital clubfoot in newborns and infants. J Pediatr Orthop 9:134–136, 1989.
19. Wesely MS, Barenfeld PA, Barrett N. Complications of the treatment of clubfoot. Clin Orthop 84:93–96, 1972.
20. Miller JH, Bernstein SM. The roentgenographic appearance of the "corrected clubfoot." Foot Ankle 6:177–183, 1986.
21. Crawford AH, Marxen JL, Osterfeld DL. The Cincinnati incision: a comprehensive approach for surgical procedures of the foot and ankle in childhood. J Bone Joint Surg 64A:1355–1358, 1982.
22. Carroll NC, Gross RH. Operative management of clubfoot. Orthopedics 13:1285–1296, 1990.
23. Applington JP, Riddle CD. Avascular necrosis of the body of the talus after combined medial and lateral release of congenital clubfoot. South Med J 69:1037–1038, 1976.
24. Haasbeek JF, Wright JG. A comparison of the long-term results of posterior and comprehensive release in the treatment of clubfoot. J Pediatr Orthop 17:29–35, 1997.
25. Herzenberg J, Radler C, Bor N. Ponseti versus traditional methods of casting for idiopathic clubfoot. J Pediatr Orthop 22:517–521, 2002.
26. Dimeglio A, Bensahel H, Souchet P, Mazeau P, Bonnet F. Classification of clubfoot. J Pediatr Orthop 4:129–136, 1995.
27. Van Langelaan EJ. A kinematic analysis of the tarsal joints: an x-ray photogrammetric study. Acta Orthop Scand 204(suppl):1–269, 1983.
28. Sarrafian SK. *Anatomy of the Foot and Ankle*, 2nd ed, pp 508–513, Lippincott, Philadelphia, 1993.
29. Root ML, Orien WP, Weed JH. *Normal and Abnormal Function of the Foot*. Clinical Biomechanics, Los Angeles, 1977.
30. Ponseti IV, Campos J. Observations on pathogenesis and treatment of congenital clubfoot. Clin Orthop 84:50–60, 1972.
31. Ponseti IV. Common errors in the treatment of congenital clubfoot. Int Orthop 21:137–141, 1997.
32. Cummings RJ, Davidson RS, Armstrong PF, Lehman WB. Congenital clubfoot. An instructional course lecture, American Academy of Orthopaedic Surgeons. J Bone Joint Surg 84A:290–308, 2002.
33. Morcuende JA, Weinstein SL, Dietz FR, Ponseti IV. Plaster cast treatment of clubfoot: the Ponseti method of manipulation and casting. J Pediatr Orthop 3:161–167, 1994.
34. Laaveg S, Ponseti IV. Long term results of treatment of congenital clubfeet. J Bone Joint Surg 62A:23–31, 1980.
35. Ponseti IV. Treatment of congenital club foot. J Bone Joint Surg 74A:448–453, 1992.
36. Cooper DM, Dietz FR. Treatment of idiopathic clubfoot. J Bone Joint Surg 77A:1477–1489, 1995.
37. Brand PW. A personal revolution in the development of clubfoot correction. Clin Podiatr Med Surg 14:1–7, 1997.
38. McKay DW. New concept of and approach to clubfoot treatment: section III—evaluation and results. J Pediatr Orthop 3:141–148, 1983.
39. Schlafly B, Butler JE, Siff SJ, Criswell AR, Cain TE. The appearance of the tarsal navicular after posteromedial release for clubfoot. Foot Ankle 5:222–237, 1985.
40. Simons GW. Complete subtalar release in clubfeet. J Bone Joint Surg 67A:1044–1055, 1985.
41. Lowe LW, Hannon MA. Residual adduction of the forefoot in treated congenital clubfoot. J Bone Joint Surg 55B:809–813, 1973.
42. Lichtblau S. Section of the abductor hallucis tendon for correction of metatarsus varus deformity. Clin Orthop 110:227–232, 1975.
43. Huson A. Functional anatomy of the foot, chapter 10. In *Disorders of the Foot and Ankle*, 2nd ed, vol 1, pp 409–431, edited by MH Jahss, Saunders, Philadelphia, 1991.
44. Ponseti IV. Relapsing clubfoot: causes, prevention, and treatment. Iowa Orthop J 22:55–56, 2002.
45. Fukuhara K, Schollmeier G, Uhthoff HK. The pathogenesis of clubfoot. A histomorphometric and immunohistochemical study of fetuses. J Bone Joint Surg 76B:450–457, 1994.
46. Zimny ML, Willig SJ, Roberts JM, D'Ambrosia RD. An electron microscopic study of the fascia from the medial and lateral sides of clubfoot. J Pediatr Orthop 5:577–581, 1985.
47. Shapiro F, Glimcher JJ. Gross and histological abnormalities of the talus in congenital clubfoot. J Bone Joint Surg 61A:522–530, 1979.
48. Pirani S, Zeznik L, Hodges D. Magnetic resonance imaging study of the congenital clubfoot treated with the Ponseti method. J Pediatr Orthop 21:719–726, 2001.
49. Wolff J. *Gesetz der Transformation der Knochen*. Aug Hirschwald, Berlin, 1802.

THE EFFECT OF THE INTERNET IN THE TREATMENT OF CONGENITAL IDIOPATHIC CLUBFOOT

Jose A. Morcuende, M.D., Ph.D.; Martin Egbert, M.B.A.; and Ignacio V. Ponseti, M.D.

ABSTRACT

Parents have traditionally relied on health care professionals for advice and treatment for most orthopaedic conditions, including clubfoot. However, the unprecedented access to health care information offered by the Internet is changing how parents gather information and make treatment choices. This study was designed to evaluate the effect of the Internet in the treatment of clubfoot. We performed a retrospective review of the clinical census, statistics of the Virtual Hospital web pages on clubfoot, web sites, and web based support-groups related to clubfoot from 1995 to 2002. There were 157 patients that came to our clinic for treatment, a dramatic increase compared to previous years. There were a total of 790,084 hits to the Virtual Hospital web pages, with information requested from all states and 72 countries. Interestingly, the referrals also changed with patients coming from 30 states and 8 different countries, compared to previous years when the majority came from our own state. In addition, 75% of the patients were self-referred, many of them while on treatment at outside institutions. There were 160 web sites providing information on clubfoot and 5 large support groups. There were approximately 30,000 messages (average 1000 messages/month) posted into the support clubfoot websites. After visiting Internet support groups, 125 parents transferred or initiated the care of their children to a doctor practicing the Ponseti method. In conclusion, the Internet provides a mean for parents to obtain disease-specific information in a timely manner. Parents used the support-groups to find and proffer information, share experiences and opinions, and provide encouragement. This sharing of information is affecting how parents make their treatment choices and also has the potential to induce unexpected changes in clinical orthopaedic practice.

INTRODUCTION

The digitalization of information, the ability to network, and the rapid electronic interchange of information on a worldwide basis are recognized hallmarks of today's society. The Internet, with 130,000,000 users and growing at a rate of 2% per month, is a global, independent but cooperative network system that allows remote access to data and permits its quick access in unprecedented volume.

The world of medicine has not escaped the impact of the Internet, and health-related sites are among the most frequently accessed information resources. A recent survey indicated that 70,000,000 US adults had accessed the Internet to obtain health or medical information in 2001[18]. At least 100,000 health and medical sites are on the World Wide Web, and are maintained by entities ranging from academic medical centers and professional organizations to individuals. Thousands of other online self-help and support groups, bulletin boards, and mailing lists also are available. However, how this unprecedented access to health care information is affecting the way parents make decisions on treatment options, and how those decisions could impact clinical practice are not well understood[3-6,13,16,17]. Interestingly, in 1998, a web page with information on the treatment of clubfoot as described by Ponseti was posted in the Virtual Hospital of the University of Iowa. Since then, we have witnessed a dramatic change in our referral patterns. This study was designed to evaluate the effect of the Internet in clubfoot clinical practice at our institution and how web-based information and supports groups influence parent choices for the treatment of clubfoot.

MATERIALS AND METHODS

We performed a retrospective reviewed of the clinical census at our institution for the diagnosis of clubfoot from January 1991 to December 2001. Demographic data was evaluated with respect to living address, referral entity (self-referral or physician referral), age of the patient at presentation, previous treat-

---

Investigation performed at the Department of Orthopaedic Surgery University of Iowa, Iowa City, IA

Correspondence and reprint requests to:
Jose A. Morcuende, MD, PhD
Department of Orthopaedic Surgery
200 Hawkins Drive
Iowa City, IA 52242
(319) 384-8041
jose-morcuende@uiowa.edu

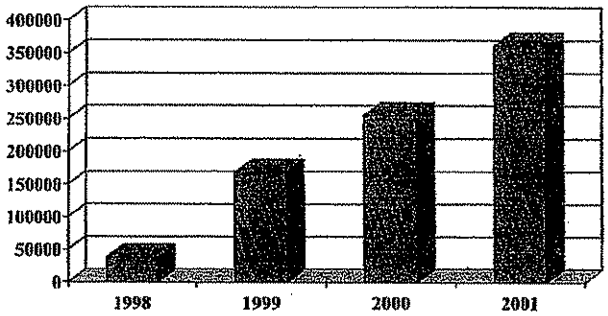


Figure 1. Number of hits at the Virtual Hospital clubfoot web page. Note the increase over the short period of time, to a total of 790,084.

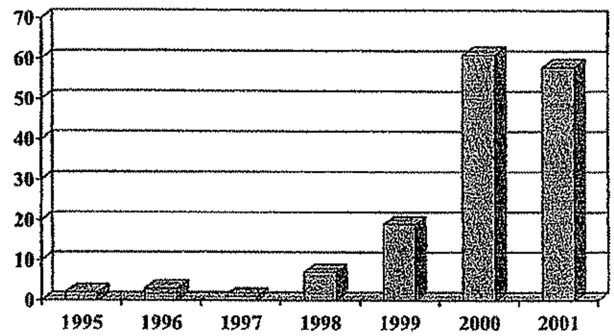


Figure 2. Number of patients seen in clinic from 1995 to 2001. Note the dramatic increase since 1998 when the Virtual Hospital clubfoot web pages were posted.

ment and type of treatment at the outside institution. We also performed a review of the statistics of the Virtual Hospital web pages for the treatment of clubfoot. Total number of hits, number of pages visited, and total visits were recorded. In addition, location of the request was also recorded.

We also performed a review of the public web sites providing information on clubfoot, as well as parent-support groups for clubfoot from October 1998 to December 2001. From the 5 most active sites, total number of members, new members per month, and total number of messages posted were recorded. In addition, evaluation of the content of the messages was performed, specifically information on decision making by the parents about treatment choices.

RESULTS

From the initial posting of the web pages on clubfoot in the Virtual Hospital in October 1998 through December 2001, there were 790,084 hits, with an average of 27,334 hits/month (Figure 1). Information was requested from all states and 72 countries. These included countries such as India, Singapore, Spain, Egypt, Australia, etc.

When evaluating patient referrals to the clinic, we observed there was an increase in the number of patients per year that paralleled the hits to the Virtual Hospital clubfoot web pages (Figures 1 and 2). In the years prior to 1998, there were an average of 5 patients seen in clinic by the senior author (IVP). This number increased to about 60 patients per year by 2001 (for a total of 157 patients). Interestingly, 75% of patients attending the clinic were self-referrals, with 71% having had treatment or currently on treatment at an outside institution.

Age at presentation demonstrated a significant difference between pre and post Internet web page posting. Patients in the early 90's were seen usually in their first month of life. After 1998, the average age at presentation was 3 months, with a range from newborn to 22 months of age. Eighteen per cent of the patients were older that 6 months at presentation (data not shown).

With regard to the parents-support groups, there were over 160 web sites providing information on clubfoot and 5 large support groups. There are sites and support groups for General Information, Surgery, Ponseti method, French Physiotherapy method, as well as parental sites in the UK, Australia, France, Germany and other countries. In the past few years, the fastest growing sites and topics have been related to conservative methods such as the Ponseti method (Figure 3). We have observed an increased number of people using group sites to obtain information and advice, with the growth of 40 new members per month.

There were approximately 30,000 messages (average 1,000 messages/month) posted on these websites and the messages are publicly available (Figure 4). Compared to the other sites, the Ponseti site had the greatest increase in number of messages. Importantly, after visiting the support groups and talking with active members in the groups, 125 parents brought their children to our institution, or to another institution where there are professionals practicing the Ponseti method. Interestingly, only 3 of these children required extensive corrective surgery after they were treated by the Ponseti method.

DISCUSSION

The results of this study, using clubfoot as a model, demonstrate that the Internet can have a profound effect in clinical practice patterns, and in the patient physician relationship. Since the introduction of information about clubfoot on the Virtual Hospital by the senior author (IVP), we have seen a dramatic increase in the

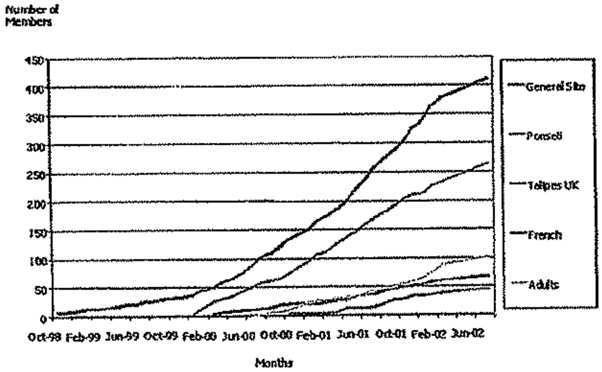


Figure 3. Total number of members at Internet sites. Note the exponential increase in the number in the general web sites and in the Ponseti method.

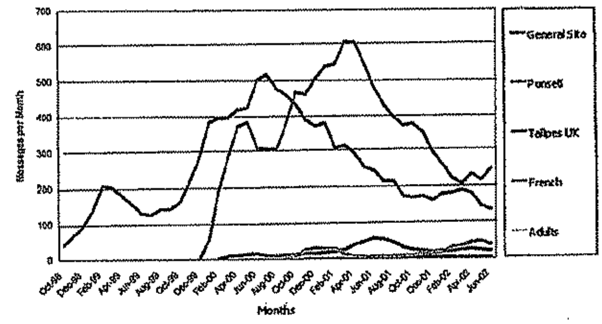


Figure 4. Number of messages posted at the different web sites. Note the correlation between the number of messages in the general site and the Ponseti web site (four months weighted average).

number of patients attending our clinic, with the majority of them coming from out of state and a significant number having been treated at an outside institution. In addition, general information and parent support groups for clubfoot have grown almost exponentially. Importantly, many parents decided to change treating physicians after consulting and sharing information on the web.

Increasing use of the Internet by consumers in general is being reflected in greater reliance on this medium for health information and health care. In part, the use of the Internet to find answers to health-related questions has been linked to several issues affecting existing practice patterns. Many people are using the Internet due to the belief that today's doctor-patient relationship lacks attention to detail and the personal touch that was present in the past. Patients also desire more involvement in and control over the management of their own health. Furthermore, there are alternatives to traditional providers and methods of treatment, and patients can not only find them on the Internet, but also retrieve information that is stated objectively and many times, non-technically. Finally, the Internet also offers a means to get a "second opinion" without the hassles of a referral and can provide a way to communicate with others patients or families in similar situations or with similar problems[3-6,13,16,17].

In the case of clubfoot, several of these issues seemed to be responsible for the changes observed in our practice. Until recently, non-surgical methods of correction have demonstrated a low success rate, with up to 90% of the patients requiring extensive corrective surgery. However, clubfoot surgery is frequently associated with persistent stiffness of the foot, and may lead to many complications (up to 25% of cases) and the need for secondary procedures (up to 47% of cases). Acceptance of these poor results, however, has been the "norm" because clubfoot has been viewed as a surgical deformity, very difficult to correct[1,2,7,9,10,11,12,14,15,19,20,23-28].

Given that the results of surgical treatment can be so discouraging, parents looked for alternative treatments. Traditionally, parents would have relied on health care professionals for advice and treatment. However, the development of the Internet and the explosion of health care information allowed them to obtain disease-specific information in a timely manner. In addition, parents created and actively used Internet support-groups on clubfoot to find and proffer information, share experiences and opinions, and provide encouragement to other parents.

From information available through the Internet, parents became aware of the Ponseti method, and of the controversy that existed over the need or not for extensive surgical treatment for the correction of the deformity. Interestingly, clubfoot is a very "visual" deformity, i.e., it is very easy for the parents to see and assess the results of any treatment. The fact that the Ponseti method allows full correction of the deformity in a very short period of time and without the need for extensive surgery is of critical importance[8,21,22]. Parents realized the benefit of this treatment modality and share their experience with others. As a result, the number of messages on the Ponseti method at the different clubfoot web sites and parents support groups increased exponentially. This also resulted on many parents transferring the care of their child to a physician with knowledge on the Ponseti method (75 % of our referral population and 125 parents in the support groups).

In conclusion, the Internet provides a mean for parents to obtain disease-specific information in a timely manner. Parents use the support-groups to find and proffer information, share experiences and opinions, and provide encouragement. This sharing of information is affecting how parents make their treatment choices and also has the potential to induce unexpected changes in clinical practice. The implications of these effects deserve further investigation.

REFERENCES

1. **Aronson J and Puskarich CL.** Deformity and disability from treated clubfoot. *J Pediatr Ortho.* 1990; 10:109-112.
2. **Atar D, Lehman WB, Grant AD.** Complications in clubfoot surgery. *Orthop Rev.* 1991; 20:233-239.
3. **Bader SA, Braude RM.** "Patient Informatics": creating new partnerships in medical decision making. *Acad Med.* 1998; 73:408-411.
4. **Ball MJ, Lillis J.** E-health: transforming the physician/patient relationship. *Int J Med Inf.* 2001; 61:1-10.
5. **Beall MS, Golladay GJ, Greenfield ML, Hesinger RN, Biermann JS.** Use of the Internet by Pediatric Orthopaedic outpatients. *J Ped Ortho.* 2002; 22:261-264.
6. **Blumenthal D.** Doctors in a wired world: can professionalism survive connectivity? *Milbank Q,* 2002; 80:525-546.
7. **Bradish CF, Noor S.** The Ilizarov method in the management of relapsed club feet. *J Bone Joint Surg Br.* 2000; 82:387-391.
8. **Cooper DM, Dietz FR.** Treatment of Idiopathic Clubfoot. A thirty-year follow- up. *J Bone Joint Surg Am.* 1995; 77:1477-1489.
9. **Crawford AH, Gupta AK.** Clubfoot controversies: complications and causes for failure. *Instr Course Lect.* 1991; 45:339-346.
10. **Crawford AH, Marxen JL, Osterfeld DI.** The Cincinnati incision: A comprehensive approach for surgical procedures of the foot and ankle in childhood. *J Bone Joint Surg Am.* 1982; 64:1355-1358.
11. **Dewaele J, Zachee B, De Vleeschauwer P, Fabry G.** Treatment of idiopathic clubfoot: critical evaluation of different types of treatment programs. *J Pediatr Ortho.* 1994; 3:89-95.
12. **Dimeglio A, Bonnet F, Mazeau Ph, De Rosa V.** Orthopaedic treatment and passive motion machine: consequences for the surgical treatment of clubfoot. *J Pediatr Ortho.* 1996; 5B:173-180.
13. **Eysenbach G, Jadad AR.** Evidence-based patient choice and consumer health informatics in the Internet age. *J Med Internet Res.* 2001; 3:E19.
14. **Grayev AM, Boal DK, Wallach DM, Segal LS.** Metaphyseal fractures mimicking abuse during treatment for clubfoot. *Pediatr Radiol.* 2001; 31:559-563.
15. **Green ADL and Lloyd-Roberts GC.** The results of early posterior release in resistant clubfeet. A long-term review. *J Bone Joint Surg Br.* 1985; 67:588.
16. **Greenes RA.** eCare and eHealth: The Internet meets health care. *J Med Pract manage.* 2001;17:106-108.
17. **Han HR, Belcher AE.** Computer-mediated support group among parents of children with cancer: an exploratory study. *Comput Nurs.* 2001; 19:27-33.
18. **Horrigan JB, Rainie L.** Counting on the Internet. Pew Internet and American Life Project. http://www.pewinternet.org . December 29, 2002.
19. **Kite JH.** Nonoperative treatment of congenital clubfoot. *Clin Orthop.* 1972; 84:29-38.
20. **Krauspe R, Vispo Seara JL, Lohr JF.** Long-term results after surgery for congenital clubfoot. *Foot and Ankle Surgery.* 1996; 2:77-82.
21. **Ponseti IV, Smoley EN.** Congenital Clubfoot: the results of treatment. *J Bone Joint Surg Am.* 1963; 45:261-275.
22. **Ponseti IV.** *Congenital Clubfoot: Fundamentals of Treatment.* Oxford, England: Oxford University Press; 1996.
23. **Simons GW.** Complete subtalar release in clubfeet. I: A preliminary report. *J Bone Joint Surg Am.* 1985; 67:1044-1055.
24. **Sobel E, Giorgini RJ, Michel R, Cohen SL.** The natural history and longitudinal study of the surgically corrected clubfoot. *J Foot Ankle Surg.* 2000; 5:305-320.
25. **Tarraf YN, Carroll NC.** Analysis of the components of residual deformity in clubfeet presenting for reoperation. *J Pediatr Orthop.* 1992; 20:233-239.
26. **Turco VJ.** Resistant congenital clubfoot: One-stage posteromedial release with internal fixation: A follow-up report of a fifteen-year experience. *J Bone Joint Surg Am.* 1979; 61:805-814.
27. **Uglow MG, Clarke NM.** Relapse in staged surgery for congenital talipes equinovarus. *J Bone Joint Surg Br.* 2000; 82:739-743.
28. **Vizkelety T, Szepesi K.** Reoperation in Treatment of clubfoot. *J Pediatr Orthop.* 1989;9:144-147.

Journal of Pediatric Orthopaedics
22:517–521 © 2002 Lippincott Williams & Wilkins, Inc., Philadelphia

Ponseti Versus Traditional Methods of Casting for Idiopathic Clubfoot

*John E. Herzenberg, M.D., †Christof Radler, M.D., and ‡Noam Bor, M.D.

Study conducted at the Maryland Center for Limb Lengthening & Reconstruction, Baltimore, Maryland, U.S.A., and the Emek Central Hospital, Afula, Israel

Summary: Serial casting is successful in avoiding extensive posteromedial release (PMR) in only 11% to 58% of patients with idiopathic congenital clubfoot. Extensive open surgery is commonly associated with long-term stiffness and weakness. Ponseti claims to avoid PMR in 89% of cases by using his specific technique of manipulation, casting, and limited surgery. The authors report their first 27 patients undergoing the Ponseti technique (34 feet) with a group of 27 matched control patients (34 feet). All patients underwent serial casting, begun within the first 3 months of life. The parameter studied was the need to perform PMR within the first year of life. In the Ponseti group, only 1 (3%) of 34 feet required PMR. In 31 (91%) of 34 feet, percutaneous Achilles tenotomy was performed at age 2 to 3 months. The average duration of casting was 2 months. In the control group, 32 (94%) of 34 feet required PMR within the first year of life, despite a longer casting period. Based on the authors' initial success with the Ponseti method, they no longer believe that PMR is required for most cases of idiopathic clubfoot. Foot abduction splints are crucial to avoid recurrence. Longer follow-up will determine whether the authors can continue to match Ponseti's reported outcomes. **Key Words:** Clubfoot—Comparison—Manipulation casting—Ponseti—Posteromedial release.

Most orthopaedic surgeons agree that the initial treatment of idiopathic congenital clubfoot should be serial gentle manipulations to stretch the contractures, with serial casting, splinting, or strapping to maintain the correction obtained by stretching (6,8,12,16,20,22,23,31,33,36). The reported success rates in standard conservative treatment are only fair, ranging from 11% to 58%. However, Ponseti claims to avoid open surgery in 89% of cases by using his technique of manipulation, casting, and limited surgery (19). Cooper and Dietz (5) reviewed Ponseti's cases, with an average of 30 years of follow-up, and found that 78% of the patients had achieved excellent or good functional and clinical outcomes compared with 85% in a control group without congenital foot deformity.

The most common clinical scenario today seems to be 3 to 5 months of serial casting, with only partial correction of the deformities being achieved. Such feet are described as being "resistant," and they then undergo a variation of posteromedial release (PMR). Various techniques for PMR in cases of resistant clubfoot have been described (3,4,6,22,33). Excellent or good results after open release surgery have been achieved in 52% to 91% of cases. However, most of these cases have relatively short follow-up periods, ranging from an average of 2 to 8 years. In the few available articles on longer-term follow-up (10–15 years) of PMR, the results are disappointing, with increasing foot pain and disability (1,8,12). In an effort to avoid the joint stiffness and muscle weakness associated with PMR, some authors have even tried application of external fixators for gradual distraction of the soft tissue (9,14,24).

Short- and medium-term complications of PMR range from simple wound infections to necrosis leading to amputation (11). Avascular necrosis of the talus has been reported (7). Overcorrections and loss of surgical correction with subsequent relapse have also been reported (33,35). Long-term complications include stiffness and weakness leading to premature arthritis of the foot (1,16). Clearly, the standard accepted practice of performing serial manipulations and then PMR in the majority of cases leads to generally excellent short-term results but disappointing long-term results. In 1997, we abandoned our previous protocols of short leg casting and PMR. In its place, we adopted Ponseti's method. In this preliminary study, we compared our first 27 patients treated with the Ponseti method with a matched control group of patients who underwent standard casting. The parameter in question was the need to perform PMR during the first year of life.

Address correspondence and reprint requests to John E. Herzenberg, M.D., Sinai Hospital, Rubin Institute for Advanced Orthopedics, International Center for Limb Lengthening, 2401 West Belvedere Avenue, Baltimore, MD 21215, U.S.A. (e-mail: FRCSC@aol.com).

From the *Maryland Center for Limb Lengthening & Reconstruction, Baltimore, Maryland, U.S.A.; †University of Vienna Medical School, Vienna, Austria; and the ‡Emek Central Hospital, Afula, Israel.

DOI: 10.1097/01.BPO.0000018893.25321.FE

METHODS

We began using Ponseti's method in mid-1997. This report describes the outcomes (need for PMR surgery) for our first 27 patients with idiopathic congenital clubfoot who were treated with this method during a 2-year period. There were 20 unilateral and 7 bilateral cases, for a total of 34 feet. Each of the patients underwent casting by one of the senior authors (J.E.H. or N.B.) starting within the first 2 weeks of life, except two patients for whom casting was delayed until ages 2 and 3 months because of later presentation. None of the patients in the Ponseti group had undergone casting before presentation at our institutions. The cases were classified according to the stiffness of the foot into categories of mild, moderate, and severe (10).

Treatment was started as soon as possible after birth (Fig. 1A–D) and consisted of weekly manipulations and long leg casting, as described by Ponseti (26,27). We strove as much as possible to reproduce Ponseti's strict casting protocol faithfully. This calls for forefoot abduction with counter-pressure on the neck of the talus, never pronating and never touching the calcaneus. If residual equinus was observed after 4 to 8 weeks of casting and the foot had been abducted 60°, a percutaneous Achilles tenotomy (complete tenotomy, not lengthening) was then performed with the patient under local or general anesthesia, and the foot was maximally dorsiflexed. After tenotomy, one more cast was applied and left in place for 3 weeks to allow healing of the tenotomy (Fig. 2A–B). When this last cast was removed, all children were treated with abduction splinting with straight-last shoes and a Denis Browne-style bar set at 45° external rotation for the normal foot and 70° for the clubfoot. (For bilateral cases, both feet are set at 70° of external rotation.) The protocol for this foot abduction orthosis was 23 hours per day for the first 3 months and then nighttime only for 2 to 4 years. This process is essential to avoid recurrence.

From our computer databases, we created a control group, matched to the Ponseti group by bilateralism and severity. The 34 clubfeet of the 27 patients in the historical control group were treated with various serial casting techniques, either by one of the senior authors (82% of the feet) or by referring physicians (18% of the feet). The end point for this study was the need for open

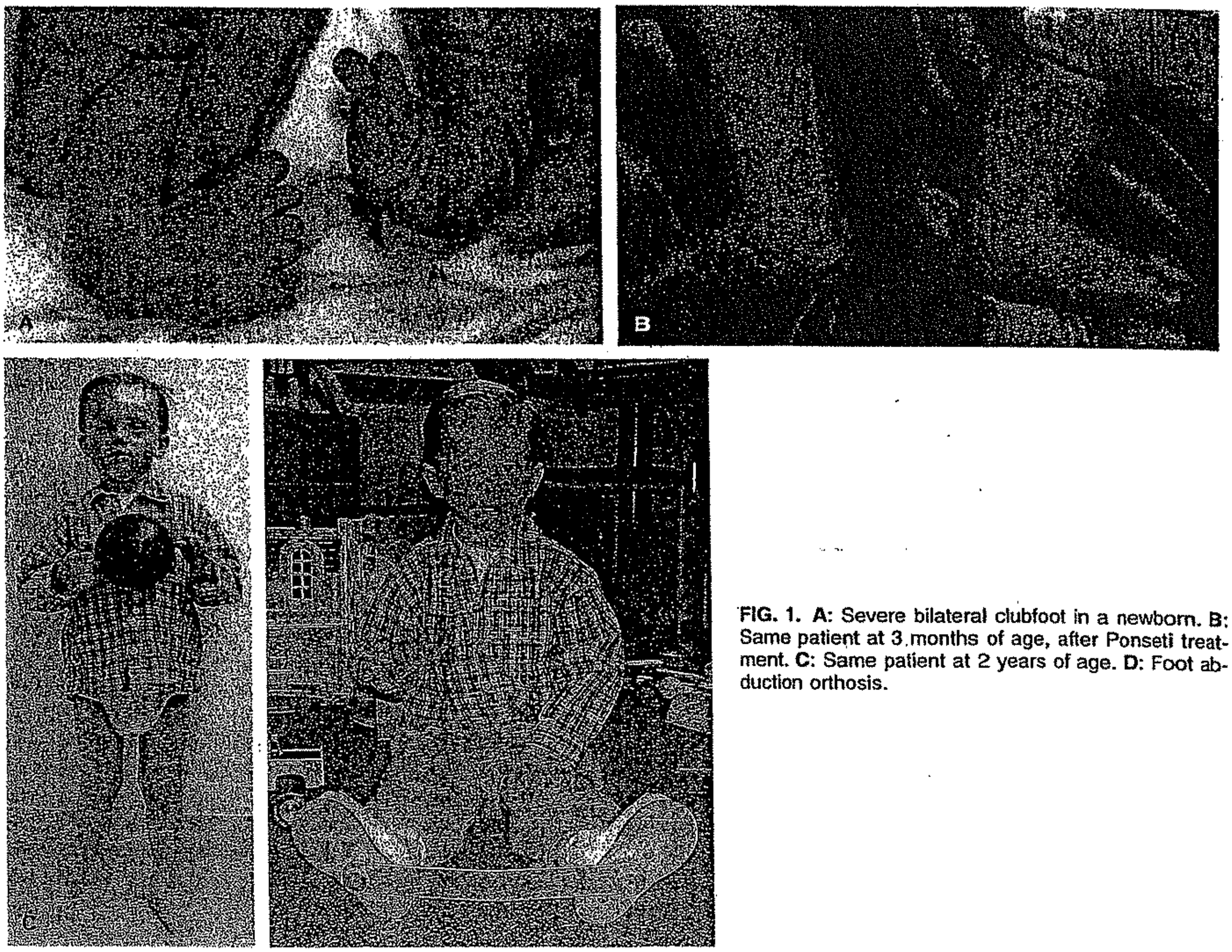


FIG. 1. A: Severe bilateral clubfoot in a newborn. B: Same patient at 3 months of age, after Ponseti treatment. C: Same patient at 2 years of age. D: Foot abduction orthosis.

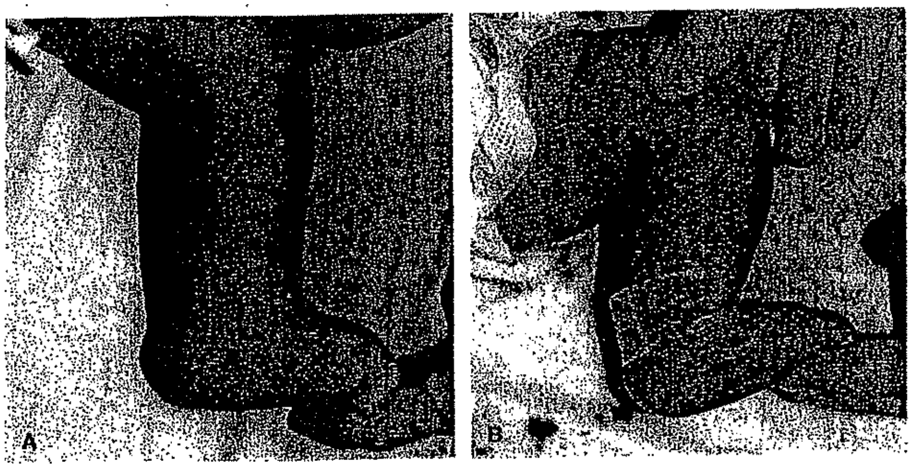


FIG. 2. Clubfoot that underwent casting with the Ponseti method is shown **(A)** before tenotomy and **(B)** after tenotomy.

surgical release (PMR) within the first year of life, as determined by the clinical judgment of one of the senior authors. We also recorded the range of dorsiflexion and plantarflexion in both groups at last follow-up.

RESULTS

Twenty-six of the 27 patients treated with the Ponseti technique were followed for at least 1 year. Twenty-five of the 27 control patients were followed for at least 1 year. The Ponseti group had an average follow-up of 25 months, and the control group had an average follow-up of 30 months. The clubfeet in the Ponseti group underwent casting initially for an average of 2 months (range 1–3), with an average of seven casts (range 3–10). Of the 34 Ponseti clubfeet, 31 (91%) underwent percutaneous Achilles tendon tenotomy. In 1 (3%) of the 34 Ponseti feet, the initial correction was good, but the family was noncompliant with use of the foot abduction orthosis and the foot relapsed, necessitating PMR.

The control group was treated with initial serial casting with short casts for 3 months (range 2–6). PMR had to be performed in 32 (94%) of 34 feet within the first year of life. One of the two control patients who were treated successfully with casting alone showed good initial results but eventually required surgery in the form of tendon lengthening procedures and transfer at age 2 years.

At follow-up, the 34 feet that were successfully treated using the Ponseti method showed good subtalar motion, dorsiflexion of 32° (range 10°–45°), and plantarflexion of 50° (range 25°–70°). The feet available for measuring in the control group (15 of 19 feet) showed diminished subtalar motion, dorsiflexion of 8° (range 5°–20°), and plantarflexion of 29° (range 10°–40°). These results show a significant difference between the PMR and Ponseti methods of treatment in terms of range of motion (dorsiflexion, $P < 0.05$, and plantarflexion, $P < 0.05$, using unpaired two-tailed t test for both).

DISCUSSION

Although the Ponseti group represented our learning curve with this method, we are very satisfied with the initial results. Only one of our patients treated with the Ponseti method required PMR, and this was attributed to noncompliance with the foot abduction orthosis regimen. At the end of casting, this patient's foot was well corrected. However, the family was not compliant with the derotation splinting, and the deformity relapsed. Another three casts were applied, which recorrected the deformity, but even then, the parents did not comply. Finally, PMR was performed.

The major concern in the operative treatment of congenital clubfoot is functional outcome. Numerous reports document good results for the first 10 years of life. However, as the child with clubfoot becomes an adult, the functional results often deteriorate. Open surgical release often leads to scarring and stiffening of the ankle, with resulting limitation of motion and strength (1,18,19,25–30). Aronson and Puskarich (1) studied the disability associated with various clubfoot treatment options. Their results showed that patients who underwent casting only and patients who had additional heel cord lengthening had the least deformity and disability. However, patients who had undergone PMR had reduced ankle plantarflexion motion and diminished push-off strength. Our patients who were treated with the Ponseti method had much better ankle range of motion, both in dorsiflexion and plantarflexion, than did the control patients. Macnicol et al. (21) correlated total range of ankle motion with eventual surgical outcome in a mean 10-year follow-up study of surgically released clubfeet.

Few authors describe their technique of casting precisely. Kite (17) illustrated his method in 1964 and comprehensively outlined his technique of manipulation. He recommended abducting the forefoot against pressure at the calcaneocuboid joint. Ponseti called this maneuver "Kite's error" because it blocks the correction of the hindfoot varus and internal rotation. Zimbler (36) reported poor follow-up results for 75 patients (90 feet) who were treated using the Kite method. Only 10% of the patients responded to the conservative treatment; all others required surgery. Zimbler attributed the failure of conservative treatment to the various types of clubfeet (rigid versus flexible). Shaw (32) recommended correcting the deformity through dorsiflexing and everting the calcaneus with the index finger and thumb while using the thenar eminence to bring the forefoot into abduction eversion and dorsiflexion. Vesely (34) attempted to mold the forefoot into a valgus position and the hindfoot into valgus and pronation. Both recommendations are contrary to Ponseti's principles, because forefoot pronation creates an increase of the cavus and locks the subtalar joint. Eversion of the calcaneus without first derotating it prevents its correct derotation. Similar errors can be found in casting methods described by Ikeda (13) and Karski and Wośko (15). Another important factor in clubfoot casting is the need to use long leg casts. Kite (17,18) used below-the-knee casts in children younger than 12 months. Ikeda (13) used short leg casts in all of his patients. A below-the-knee cast is not suitable for holding the foot abduction and should therefore not be used at any age.

The Ponseti method of casting for idiopathic clubfoot was successful in avoiding PMR surgery in 95% of our cases. Percutaneous tenotomy performed during the first few months of life has been shown by Cooper and Dietz (5) to be a benign procedure, with no negative long-term effect on muscle strength. Follow-up of our patients treated with the Ponseti method averaged 25 months, and we have thus far had one partial relapse that required the tibialis anterior tendon transfer that Ponseti reports as occurring in 35% of his patients older than 2.5 years (26,29). Ponseti's more recent experience suggests a relapse rate closer to 10%, the diminution being attributed to an improved appreciation of the need for careful follow-up treatment with the foot abduction orthosis protocol (Ponseti, personal communication). Derotation splinting after the casting period seems to be crucial to avoid relapse of the treated foot and should be administered by any means. A longer follow-up study of our patients is needed to evaluate final outcomes.

Bensahel et al. (2) and others from France have described a method of serial manipulations by well-trained physiotherapists to avoid PMR. However, it has been pointed out that the French treatment involves a very lengthy procedure and a long casting time and has a relatively low success rate compared with Ponseti's method (28).

One of the chief advantages to using the Ponseti method is the decreased cost, which is important in this age of cost containment. The Ponseti method and traditional casting methods use similar amounts of casting. Thus, there is very little difference in the outpatient costs. However, the traditional casting method invariably leads to an incomplete correction, necessitating an expensive surgical procedure (PMR) with the associated high cost of general anesthesia, operating room time, and hospitalization. The Ponseti treatment usually requires only a relatively inexpensive and quick office procedure (percutaneous Achilles tenotomy), with the patient under local anesthesia. The resultant savings are many thousands of dollars compared with the traditional method.

REFERENCES

1. Aronson J, Puskarich CL. Deformity and disability from treated clubfoot. *J Pediatr Orthop* 1990;10:109–19.
2. Bensahel H, Degrippes Y, Billot C. Comments about 600 club feet [in French]. *Chir Pediatr* 1980;21:335–42.
3. Carroll NC. Clubfoot: what have we learned in the last quarter century? *J Pediatr Orthop* 1997;17:1–2.
4. Carroll NC, Gross RH. Operative management of clubfoot. *Orthopedics* 1990;13:1285–96.
5. Cooper DM, Dietz FR. Treatment of idiopathic clubfoot: a thirty-year follow-up note. *J Bone Joint Surg [Am]* 1995;77:1477–89.
6. Cummings RJ, Lovell WW. Operative treatment of congenital idiopathic clubfoot. *J Bone Joint Surg [Am]* 1988;70:1108–12.
7. Cummings RJ, Bashore CJ, Bookout CB, Elliott MJ. Avascular necrosis of the talus after McKay clubfoot release for idiopathic congenital clubfoot. *J Pediatr Orthop* 2001;21:221–4.
8. Green AD, Lloyd-Roberts GC. The results of early posterior release in resistant club feet: a long-term review. *J Bone Joint Surg [Br]* 1985;67:588–93.
9. Grill F. Correction of clubfoot deformity without osteotomy by the use of the Ilizarov method. In: Simons GW, ed. *The clubfoot.* New York: Springer-Verlag, 1994:288–93.
10. Harrold AJ, Walker CJ. Treatment and prognosis in congenital clubfoot. *J Bone Joint Surg [Br]* 1983;65:8–11.
11. Hootnick DR, Packard DS, Levinsohn EM. Necrosis leading to amputation following clubfoot surgery. *Foot Ankle* 1990;10:312–6.
12. Hutchins PM, Foster BK, Paterson DC, Cole EA. Long-term results of early surgical release in clubfeet. *J Bone Joint Surg [Br]* 1985;67:791–9.
13. Ikeda K. Conservative treatment of idiopathic clubfoot. *J Pediatr Orthop* 1992;12:217–23.
14. Joshi BJ, Laud NS, Kaushik A, et al. Controlled differential distraction for correction of complex congenital talipes equinovarus. In: Simons GW, ed. *The clubfoot.* New York: Springer-Verlag, 1994:282–8.
15. Karski T, Wośko I. Experience in the conservative treatment of congenital clubfoot in newborns and infants. *J Pediatr Orthop* 1989;9:134–6.
16. Kite JH. Principles involved in the treatment of congenital clubfoot. *J Bone Joint Surg* 1939;21:595–606.
17. Kite JH. *The clubfoot.* New York: Grune & Stratton, 1964.
18. Kite JH. Nonoperative treatment of congenital clubfoot. *Clin Orthop* 1972;84:29–38.
19. Laaveg SJ, Ponseti IV. Long-term results of treatment of congenital clubfoot. *J Bone Joint Surg [Am]* 1980;62:23–31.
20. Levin MN, Kuo KN, Harris GF, Matesi DV. Posteromedial release for idiopathic talipes equinovarus: a long-term follow-up study. *Clin Orthop* 1989;242:265–8.
21. Macnicol MF, Nadeem RD, Forness M. Functional results of surgical treatment in congenital talipes equinovarus (clubfoot): a comparison of outcome measurements. *J Pediatr Orthop B* 2000;9:285–92.
22. McKay DW. New concept of and approach to clubfoot treatment: section II: correction of the clubfoot. *J Pediatr Orthop* 1983;3:10–21.
23. Nather A, Bose K. Conservative and surgical treatment of clubfoot. *J Pediatr Orthop* 1987;7:42–8.
24. Paley D. Complex foot deformity correction using the Ilizarov circular external fixator with distraction but without osteotomy. In: Simons GW, ed. *The clubfoot.* Berlin: Springer-Verlag, 1994:297–321.
25. Ponseti IV. Treatment of congenital clubfoot. *J Bone Joint Surg [Am]* 1992;74:448–54.
26. Ponseti IV. *Congenital clubfoot: fundamentals of treatment.* New York: Oxford University Press, 1996.
27. Ponseti IV. Common errors in the treatment of congenital clubfoot. *Int Orthop* 1997;21:137–41.
28. Ponseti IV: Clubfoot management. *J Pediatr Orthop* 2000;20:699–700.
29. Ponseti IV, Campos J. Observations on pathogenesis and treatment of congenital clubfoot. *Clin Orthop* 1972;84:50–60.

30. Ponseti IV, Smoley EN. Congenital clubfoot: the results of treatment. *J Bone Joint Surg [Am]* 1963;45:261–75.
31. Porat S, Milgrom C, Bentley G. The history of treatment of congenital clubfoot at the Royal Liverpool Children's Hospital: improvement of results by early extensive posteromedial release. *J Pediatr Orthop* 1984;4:331–8.
32. Shaw NE. The early management of clubfoot. *Clin Orthop* 1972; 84:39–43.
33. Turco VJ. Resistant congenital clubfoot: one-stage posteromedial release with internal fixation: a follow-up report of a fifteen-year experience. *J Bone Joint Surg [Am]* 1979;61:805–14.
34. Vesely DG. A method of application of a clubfoot cast. *Clin Orthop* 1972;84:47–9.
35. Weseley MS, Barenfeld PA, Barrett N. Complications of the treatment of clubfoot. *Clin Orthop* 1972;84:93–6.
36. Zimbler S. Nonoperative management of the equinovarus foot: long-term results. In: Simons GW, ed. *The clubfoot*. New York: Springer-Verlag, 1994:191–3.

Not all pages attached

Iowa Orthopaedic Jou
Vol. 22: 55-56, 2002

RELAPSING CLUBFOOT: CAUSES, PREVENTION, AND TREATMENT[1]

Ignacio V. Ponseti

INTRODUCTION

Regardless of the mode of treatment, the clubfoot has a strong tendency to relapse. Stiff, severe clubfeet and small calf sizes are more prone to relapse than less severe feet. Clubfeet in children with very loose ligaments tend not to relapse. Relapses are rare after four years of age.

Not all components of the clubfoot tend to relapse to the same degree. In most of our cases, forefoot correction is permanent without metatarsus adductus. The relapse of the cavus deformity is rare and usually mild. The most important relapses occur in the hindfoot, first in the equinus, and then in the heel varus. In some relapsed clubfeet, the heel varus is very severe, while in others it is mild. Rarely, the heel in equinus may go into valgus resulting in a calcaneovalgus deformity. This is a frequent occurrence in surgically treated clubfeet.

In our experience, most relapses develop gradually and may be difficult to recognize in the early stages. A relapse is detected when there is an appearance of a slight equinus and varus deformity of the heel, most often without increased adduction and cavus in the forefoot. When walking, the child tends to put more weight on the outside of the sole of the foot.

CAUSES

It is wrongly assumed that relapses occur because the deformity has not been completely corrected. Actually, relapses are caused by the same pathology that initiated the deformity. Therefore, when we understand the pathogenesis of the clubfoot, the causes of the relapse will become clear.

The clubfoot in otherwise normal children is a developmental anomaly originating after the third month of intrauterine life. It is induced by an unknown dysfunction in the posterior and medial aspects of the lower leg, ankle and foot. There is a slight decrease in size of the muscles, and an excess of collagen synthesis with retracting fibrosis in the medial and posterior tarsal ligaments, in the deep fascia, the tendo Achilles, and the posterior tibial tendon. These changes induce severe equinus, medial displacement of the navicular, heel varus and foot adduction.

The period of dysfunction causing the deformity starting in the middle third of pregnancy lasts to the third or fourth year of life. In mild cases, it may start in late fetal life, and remain active for only a few months after birth. In all cases, the resulting fibrosis is most pronounced from a few weeks preceding birth, to a few months after birth. This is the period when collagen accretion is greatest in tendons and ligaments of normal mammals and presumably also of man. The speed of growth of the foot decreases after the first year of life, diminishing greatly after five years.

Relapses appear to be related to the intensity of collagen synthesis as the foot grows. Thus, relapses occur swiftly in premature infants and more slowly in older infants. Relapses are less common and less severe in mild club feet with little fibrosis and in children with loose ligaments. They occur because the factors inducing the deformity are still active. Relapses are rare after four years of age, regardless of whether the deformity is fully or partially corrected.

The clubfoot is no different from other non-embryonic human deformities such as torticollis, scoliosis, or Dupuytren's contracture, in that it develops in normal individuals, and progresses for a limited time before becoming inactive. Torticollis usually develops within days after birth and increases for a few weeks. Idiopathic scoliosis starts in late childhood and increases throughout adolescence. Dupuytren's contracture develops at maturity and may be active for a few years. Clubfoot develops in the middle of pregnancy and is active during the first to fourth years of life. In torticollis, Dupuytren's contracture, and presumably in clubfoot, a localized temporary increase of collagen synthesis is a common pathologic feature.

With our technique, most congenital clubfeet in infants are corrected within four to six weeks. However, splinting for several months or years is indispensable to help prevent relapses. Since the main corrective force

[1] Lecture delivered at the IX National Congress of the Italian Society of Pediatric Orthopaedics and Traumatology, in Rome, October 2001.

Department of Orthopaedic Surgery
University of Iowa
Iowa City, Iowa, U.S.A.

Journal of Pediatric Orthopaedics
21:719–726 © 2001 Lippincott Williams & Wilkins, Inc., Philadelphia

Magnetic Resonance Imaging Study of the Congenital Clubfoot Treated With the Ponseti Method

Shafique Pirani, M.B.B.S., F.R.C.S.C., Laura Zeznik, M.D., and David Hodges, M.D., F.R.C.P.C.

Study conducted at the Royal Columbian Hospital, New Westminster, British Columbia, Canada

Summary: Little information exists about the degree of efficacy of the several nonoperative treatments, such as manipulation and casting, used in correcting the pathology of the virgin clubfoot deformity. The steps in the correction of the displacements and anomalies of the skeletal components have never been visualized. The method reported to have the best long-term results is that of Ponseti. A magnetic resonance imaging protocol was devised to image the described chondroosseous abnormalities of the virgin clubfoot deformity and to illustrate the changes that occur with the Ponseti method of treatment. Scans were performed at the beginning of, in the middle of, and at the end of treatment. Images obtained with this protocol largely agree with postmortem studies of clubfeet. All of the major chondroosseous pathology could be visualized in vivo. With Ponseti treatment, all the abnormalities seen on the initial scans either improved markedly or corrected completely. Treatment resulted in correction not only of the abnormal relationships of the tarsal bones, but also of the abnormal shapes of the individual tarsal osteochondral anlages, probably because of the changes in growth resulting from the changes in mechanical loading of fast-growing tissues. **Key Words:** Clubfoot deformity—MRI evaluation—Ponseti treatment—Remodeling.

Nonoperative treatment of the virgin clubfoot, such as manipulation and casting, has been used to correct the deformity since the time of Hippocrates (1,2,7,8,10). Little information exists about the degree of efficacy of the several methods used in correcting the pathology of the deformity. The method reported to have the best long-term results is that of Ponseti. A 34-year follow-up of his patients by Cooper and Dietz (4) has reported 78% good and excellent results. The steps in the correction of the displacements and anomalies of the skeletal components have never been visualized.

The deformity occurs mainly in the tarsus (10). In radiographs of infants the centers of ossification, small and oblong, can be seen in the talus and calcaneus. No ossification is present in the navicular. With ultrasound, various elements of the deformity are seen, but no evaluations can be made through a cast (5).

In the past, magnetic resonance imaging (MRI) investigations have mostly been one-time evaluations; hence, they show snapshots of different clubfeet at different stages during treatment, at different ages (3,9,11,12,14). These investigations have largely been directed toward identifying and measuring various aspects of the chondroosseous deformities rather than evaluating the effects of treatment.

With MRI, we have a unique opportunity to image the chondroosseous elements of the clubfoot in many planes and to evaluate the effects of treatment. The aims of the current study were to develop an MRI protocol that would allow us to image the various chondroosseous abnormalities described in anatomic studies, and to describe the effect of manipulation and cast treatment by the Ponseti method on these chondroosseous abnormalities by sequential MRI evaluation during treatment.

METHODS

Since 1997, infants with virgin clubfeet referred to our clinic have been treated with the Ponseti method of manipulation and casting. An MRI protocol was devised to image all the anatomic abnormalities reported and to illustrate changes that occurred with the treatment. Scans are performed at the beginning of treatment (typically after the first manipulation and cast application), in the middle of treatment (typically after the third or fourth manipulation and cast application), and at the end of treatment (typically after percutaneous Achilles tenotomy and application of the last cast). Infants arrive at the MRI scanner sleep-deprived and are then fed to induce sleep. If necessary they are given chloral hydrate for sedation (50–75 mg/kg). The casted foot is placed within an adult wrist coil. Fast spin-echo T2-weighted sequences are used because they are short in duration and

Address correspondence and reprint requests to Shafique Pirani, Associate Professor, Department of Orthopaedics, Royal Columbian Hospital, University of British Columbia, 205-245 East Columbia Street, New Westminster, British Columbia, Canada, V3L 3W4 (e-mail: iras@aol.com).

From Royal Columbian Hospital, University of British Columbia, New Westminster, British Columbia, Canada.

provide good contrast between bone and cartilage. Slice thickness is 2.0 mm, with no gap. Our studies were performed in a high field-strength magnet (GE 1.0 Tesla; General Electric Medical Systems, Milwaukee, WI).

Images are obtained as follows:

1. Sagittal images perpendicular to the bimalleolar axis (to image tibiotalar plantarflexion, inferior talar neck inclination, and inferior talonavicular displacement)
2. Oblique axial images perpendicular to the talonavicular joint (to image medial talar neck inclination, medial talonavicular displacement, the wedge-shaped head of the talus, and the wedge-shaped navicular)
3. Oblique axial images perpendicular to the calcaneocuboid joint (to image the wedge-shaped distal calcaneus and medial calcaneocuboid displacement)
4. Oblique coronal images perpendicular to the subtalar joint (to image the inverted and adducted calcaneus and the abnormal facets of the subtalar joint).

The parameters of the sequence are as follows: repetition time, 2,500 ms; echo time, 80 ms effective, echo train of 12; bandwidth 16 kHz; field of view, 12 × 12 cm, with a matrix of 256 × 192. Three acquisitions are obtained to provide a good signal-to-noise ratio. Scanning time is approximately 2 minutes 10 seconds per sequence.

For each foot, after completion of the sequential scans, all MRI films were reviewed and representative cuts selected. Initially the scans were of poor quality, but with modifications in our protocol we could improve the imaging quality so that with our current protocol we can visualize most if not all of the chondroosseous abnormalities mentioned later. Twelve clubfeet in 12 infants have been evaluated by MRI. We are showing scans from three feet in three patients representative of our findings. The changes are qualitative rather than quantitative.

Case 1

A 2-month-old boy was seen with bilateral clubfeet, treated elsewhere for 2 months with below-knee casts (Fig. 1). We treated the feet according to the Ponseti method. The feet were clinically corrected in five casts. To prevent relapse, a foot abduction splint was applied. Three sequential MRI examinations were performed of the right clubfoot as per our protocol: after application of the first cast, after application of the third cast, and after percutaneous tenotomy and application of the fifth cast. The interval between each MRI evaluation was 2 weeks.

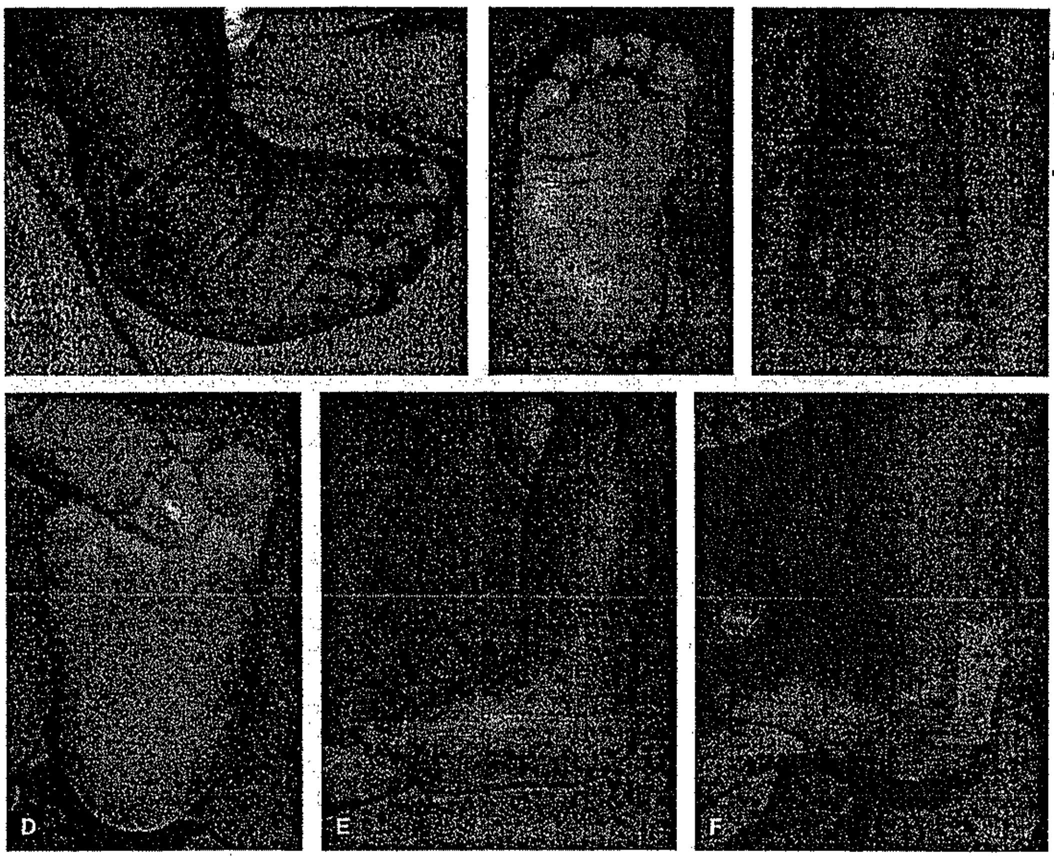


FIG. 1. Clinical photographs of the right foot in patient 1. The infant was referred at age 2 months with a history of weekly manipulations and below-knee casts. Physical examination showed persisting deformity with equinus and varus of the hindfoot (A) and adductus and cavus of the midfoot (B). After treatment with four manipulations and casting per the Ponseti method there was complete clinical correction of the varus, adductus (C, D), and cavus (D, E). After a percutaneous Achilles tenotomy, the foot could be dorsiflexed 15° at the ankle (F).

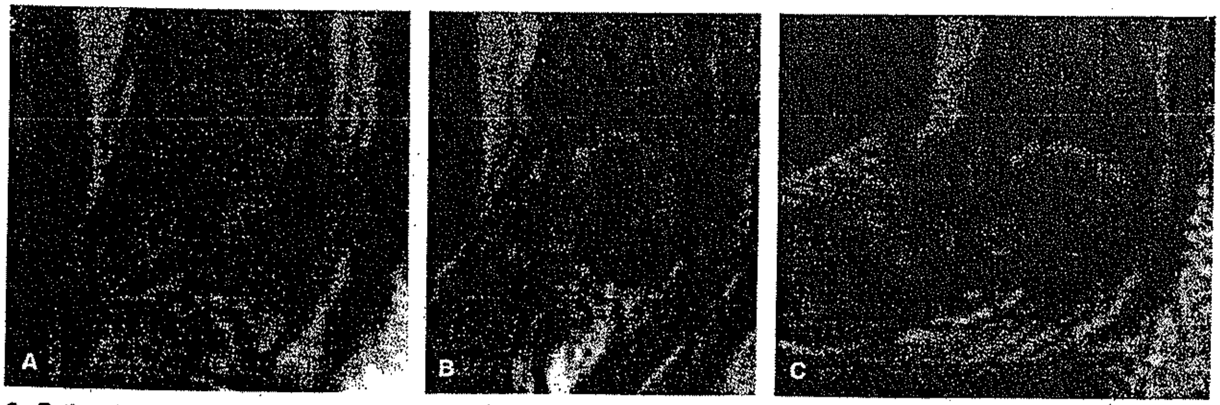
IG. 2. Clubfoot of a 3-day-old infant showing severe tibiotalar plantarflexion, medial and plantar talar neck inclination, a wedge-shaped ead of the talus, and severe medial displacement, adduction, and inversion of the navicular such that it articulates only with the medial spect of the head of the talus, leaving the lateral part of the head uncovered. The medial tuberosity of the navicular approaches the edial malleolus. The navicular is wedge-shaped, and the calcaneus is adducted and inverted such that the anterior tuberosity of the lcaneus lies under the head of the talus rather than lateral to it (**A**). Only the medial part of the wedge-shaped anterior tuberosity of e calcaneus articulates with the cuboid (**B**), which is displaced medially and inverted in front of the calcaneus. (Courtesy of Dr. I. V. onseti, Iowa City, Iowa.)

'hen interpreting the MRI scans, we found it useful to fer to the picture of a dissected clubfoot to correlate the ıages with the chondroosseous pathoanatomy (Fig. 2). The sagittal images perpendicular to the bimalleolar is show the correction of the tibiotalar plantar-flexion ıd inferior talonavicular displacement from the first to e third scans (Fig. 3). The oblique axial images perndicular to the talonavicular joint show the correction the medial talar neck inclination, the medial talonacular displacement, the wedge-shaped head of the tas, and the wedge-shaped navicular from the first to the ird scans (Fig. 4). The oblique axial images perpencular to the calcaneocuboid joint show the correction the wedge-shaped distal calcaneus and the medial lcaneocuboid displacement from the first to the third ans (Fig. 5). The oblique coronal images perpendicular to the subtalar joint show the correction of the inverted calcaneus from the first to the second scans (Fig. 6).

Case 2

A 2-week-old boy was referred with a virgin right clubfoot. His feet were treated according to the Ponseti method, and a complete correction was obtained. The first cast was applied at age 2.5 weeks. Three sequential MRI examinations were performed of the right clubfoot per our protocol (after application of the first cast, after application of the fourth cast, and after percutaneous tenotomy and application of the seventh cast). The foot was then treated with a foot abduction splint.

The oblique axial images perpendicular to the calcaneocuboid joint show the correction of the wedge-shaped distal calcaneus, the medially inclined calcaneocuboid



. 3. Patient 1. Sequential sagittal magnetic resonance images perpendicular to the bimalleolar axis show progressive correction of tibiotalar plantarflexion and inferior talonavicular subluxation from the first cast (**A**) to the third cast (**B**) to the fifth cast applied after utaneous tenotomy (**C**).

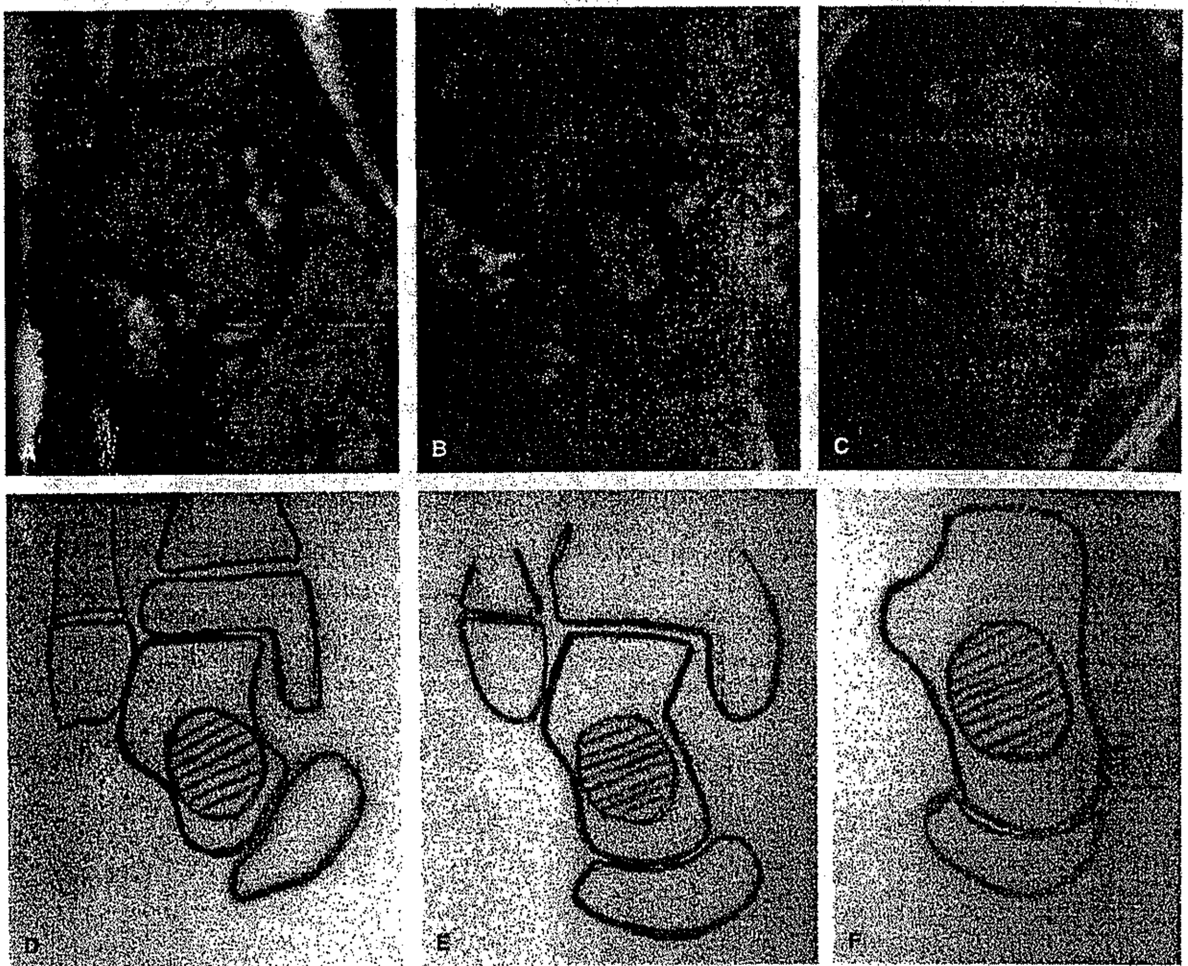


FIG. 4. Patient 1. Sequential oblique axial magnetic resonance images perpendicular to the talonavicular joint show progressive correction of the medial talar neck inclination, the medial talonavicular displacement, and the wedge-shaped navicular from the first cast (**A**) to the third cast (**B**) to the fifth cast applied after percutaneous tenotomy (**C**). With the application of the fifth cast, the medial talar neck inclination was reduced to normal and the talonavicular joint was reduced anatomically and congruent. **D—F**: Tracings of the correction of the medial talar neck inclination and the medial talonavicular displacement.

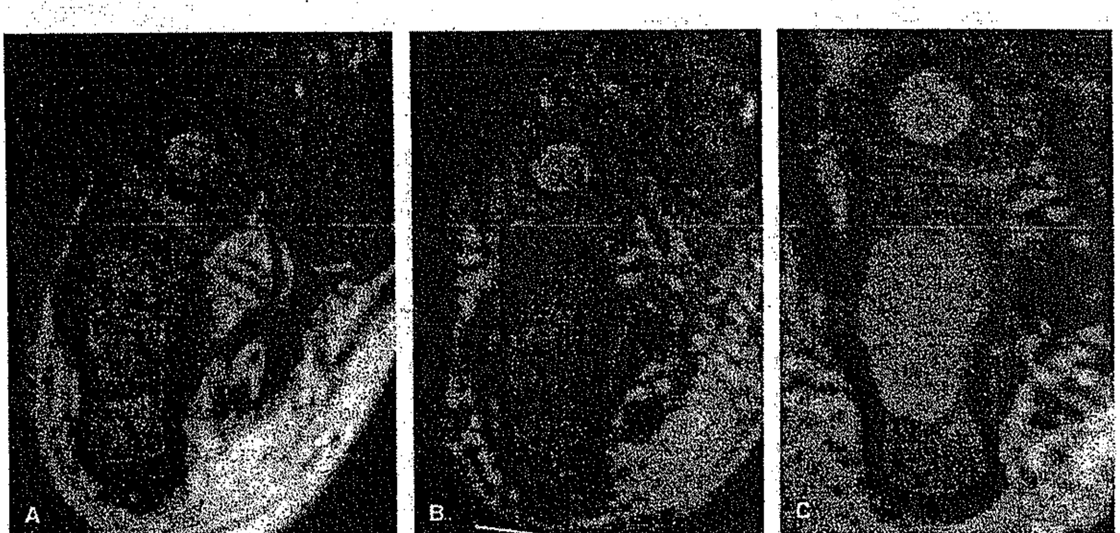


FIG. 5. Patient 1. Sequential oblique axial magnetic resonance images perpendicular to the calcaneocuboid joint show the correction of the wedge-shaped distal calcaneus, the medially inclined calcaneocuboid articular surfaces, and the medial calcaneocuboid displacement from the first cast (**A**) to the third cast (**B**) to the fifth cast applied after percutaneous tenotomy (**C**). After application of the fifth cast, the calcaneocuboid joint was anatomically reduced and congruent.

FIG. 6. Patient 1. Sequential oblique coronal magnetic resonance images perpendicular to the posterior facet of the subtalar joint show that the inverted calcaneus in the first cast (**A**) was well aligned in the third cast (**B**).

rticular surfaces, and medial calcaneocuboid displacement from the first to the third scans (Fig. 7). The oblique axial images perpendicular to the talonavicular joint show the correction of the medial talar neck inclination, the medial talonavicular displacement, the wedge-shaped head of the talus, and the wedge-shaped navicular from the first to the third scans (Fig. 8), without a marked change in the shape or orientation of the ossific nucleus of the talus.

Case 3

An 11-month-old girl with a left clubfoot was seen; she had been treated elsewhere for 11 months intermittently with below-knee casts. Her feet were then treated according to the Ponseti method. They clinically improved but did not correct completely (Fig. 9).

The oblique axial images perpendicular to the calcaneocuboid joint show that the wedge-shaped distal calcaneus and medial calcaneocuboid displacement improved but did not correct completely. The sagittal images perpendicular to the bimalleolar axis show how the plantarflexion deformity of the calcaneocuboid joint corrected with remodeling and realignment. However, a new iatrogenic deformity became apparent, with an upturning of the distal end of the calcaneus, making the profile of the calcaneus similar to that of a Dutch wooden clog.

DISCUSSION

Of the various descriptions of the pathoanatomy of the clubfoot deformity, we find the one by Ponseti (10) the

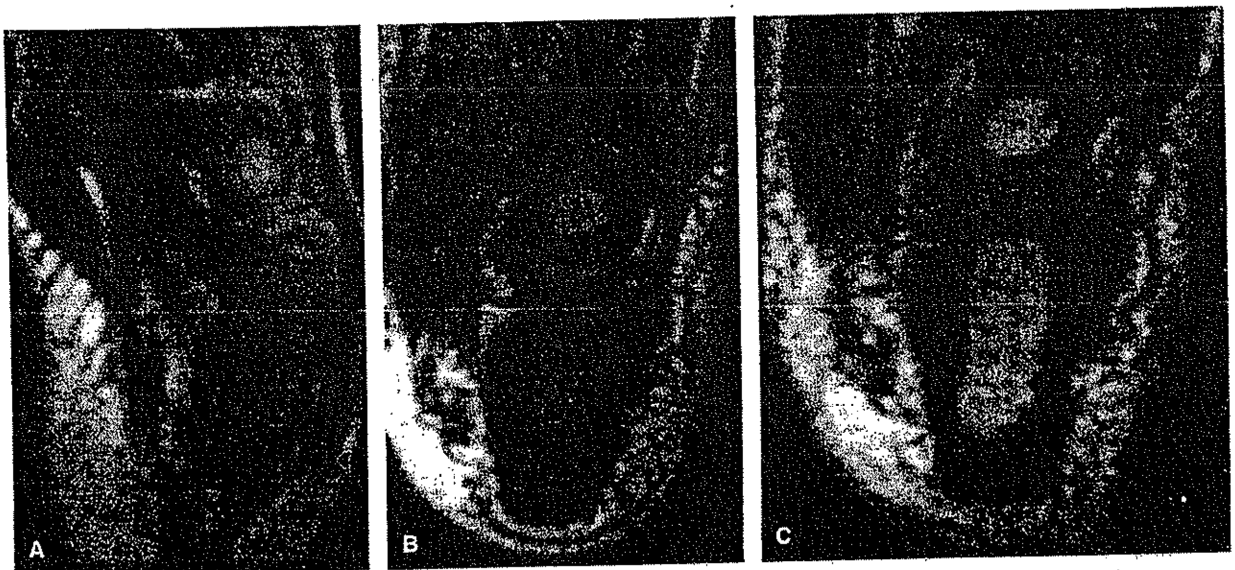


FIG. 7. Patient 2. Sequential oblique axial magnetic resonance images perpendicular to the calcaneocuboid joint show progressive correction of the wedge-shaped distal calcaneus, the medially inclined calcaneocuboid articular surfaces, and the medial calcaneocuboid displacement from the first cast (**A**) to the fourth cast (**B**) to the seventh cast applied after percutaneous Achilles tenotomy (**C**). After the seventh cast, the medially inclined calcaneocuboid articular surfaces were well aligned in their more normal attitude perpendicular to the calcaneus, and the calcaneocuboid joint was anatomically reduced and congruent.

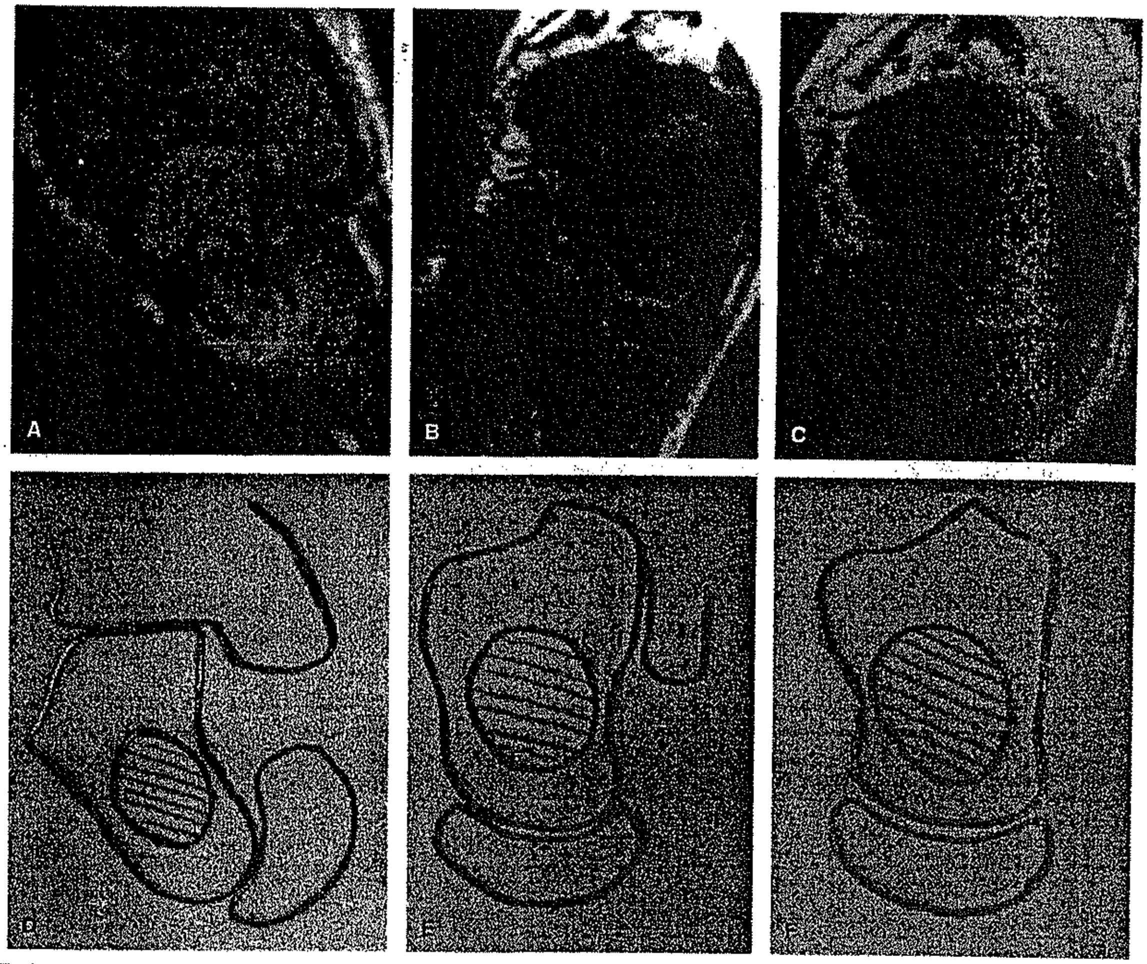


FIG. 8. Patient 2. Sequential oblique axial magnetic resonance images perpendicular to the talonavicular joint show progressive correction of the medial talar neck inclination, the medial talonavicular displacement, the wedge-shaped head of the talus, and the wedge-shaped navicular from the first cast (**A**) to the fourth cast (**B**) to the seventh cast applied after percutaneous tenotomy (**C**). In the seventh cast, the medial talar inclination was reduced to normal and the talonavicular joint was reduced anatomically and was congruent. **D–F:** Tracings of the correction of the medial talar neck inclination and the medial talonavicular displacement.

most germane to this discussion (Fig. 2). Images obtained with our MRI protocol largely agree with his postmortem studies of clubfeet, and we could visualize in vivo the following chondroosseous pathology:

1. Severe tibiotalar plantarflexion such that only the posterior part of the body of the talus articulates with the mortise
2. Medial talar neck inclination
3. A wedge-shaped head of the talus
4. Severe medial displacement, adduction, and inversion of the navicular such that it articulates only with the medial tuberosity of the head of the talus, leaving the lateral part of the head uncovered. The medial pole of the navicular approaches the medial malleolus.
5. A wedge-shaped navicular
6. An adducted and inverted calcaneus such that the anterior tuberosity of the calcaneus lies under the head of the talus rather than lateral to it
7. A wedge-shaped distal calcaneal articular surface. The cuboid is medially displaced and inverted in front of the calcaneus. Only the medial part of the anterior tuberosity of the calcaneus articulates with the cuboid.

The guidelines for clubfoot treatment as stated by Ponseti (10) include:

1. All components of the clubfoot deformity must be corrected simultaneously, not in sequence, except for the equinus, which should be corrected last.
2. The cavus, which results from pronation of the forefoot in relation to the hindfoot, is corrected together with the adduction by supinating and abducting the forefoot in proper alignment with the hindfoot.
3. With the arch well molded and the foot in slight supination, the entire foot can be gently and gradually abducted (outward rotation) under the talus, which is secured against rotation in the ankle mortise, by applying counterpressure with the thumb against the lateral aspect of the head of the talus. Heel varus will be corrected when the entire foot is fully abducted (never everted, but in maximum outward rotation) under the talus. The heel is not touched.

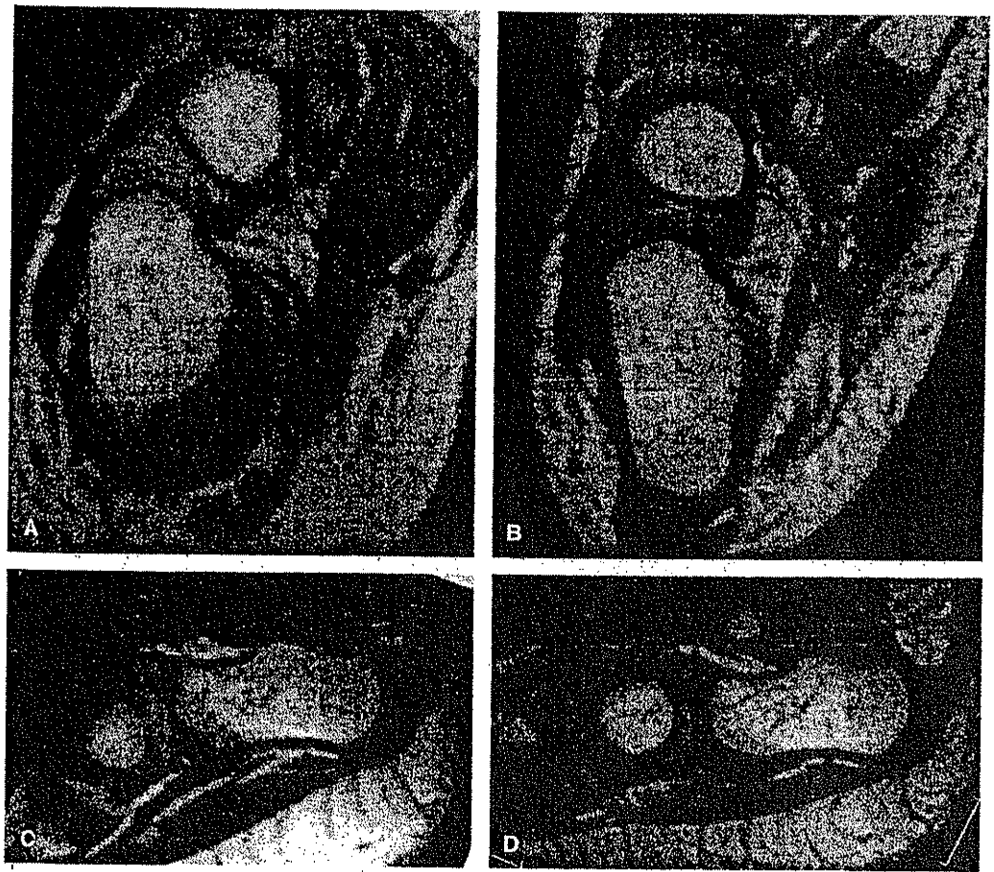


FIG. 9. Patient 3. Oblique axial magnetic resonance images perpendicular to the calcaneocuboid joint show that the wedge-shaped distal calcaneus and the medial calcaneocuboid displacement improved but did not correct completely from the first scan at 11 months of age (**A**) to the third scan at 14 months of age (**B**). The sagittal images perpendicular to the bimalleolar axis show the plantarflexion deformity of the calcaneocuboid joint (**C**) and its response to manipulation and casting by the Ponseti method. The deformity corrected with remodeling and realignment of the distal calcaneal articular surface to a more normal orientation, where it is perpendicular to the long axis of the calcaneus. The cuboid remodeled so that its proximal and distal articular surfaces became more parallel. However, a new iatrogenic deformity became apparent, with an upturning of the distal end of the calcaneus, making the profile of the calcaneus similar to that of a Dutch wooden clog (**D**).

4. Finally, the equinus is corrected by dorsiflexing the foot. This is generally facilitated by a simple percutaneous tenotomy of the Achilles tendon.
5. Well-molded plaster casts are applied weekly after manipulations.

We followed these guidelines during our treatment and performed sequential MRI evaluations to see what effect our treatment was having on the chondroosseous abnormalities described. With the Ponseti treatment, in patients 1 and 2 all the abnormalities seen on the initial scans either improved markedly or corrected completely. The sagittal images perpendicular to the bimalleolar axis documented correction of severe tibiotalar plantar flexion and inferior talonavicular subluxation. The oblique axial images perpendicular to the talonavicular joint documented correction of the wedge-shaped head of the talus, the medial talar neck inclination, and the medial displacement, adduction, and inversion of the navicular. The oblique axial images perpendicular to the calcaneocuboid joint documented correction of the wedge-shaped distal calcaneus, the medially inclined calcaneo cuboid articular surfaces and the medially displaced and inverted cuboid. The oblique coronal images perpendicular to the subtalar joint show how the inverted calcaneus everts to a normal position. The changes occur mostly in the cartilage without much alteration in the shape and orientation of the underlying ossification centers.

This study shows that Ponseti manipulation and cast treatment of the clubfeet in our series leads not only to correction of the abnormal relationships of the tarsal bones but also to the correction of the abnormal shapes of the individual tarsal bones, probably because of the changes in mechanical loading of fast-growing tissues. The sequential MRI images show that the static loading induced by the gradual and gentle correction of the clubfoot with the Ponseti technique does not cause stunting of the growth of the fast-remodeling cartilage covering the partly ossified tarsal bones, as concluded by Hueter (6) and Volkmann (13). Rather, the cartilage in the tarsal bones remodels with changes in the direction of the stresses, as Wolff (15) observed occurring in bone.

Our study supports Ponseti's statement (10) that "A well-conducted orthopedic treatment, based on a sound understanding of the functional anatomy of the foot, and on the biologic response of young connective tissue and bone to changes in direction of mechanical stimuli, can gradually reduce or almost eliminate these deformities in most clubfeet."

Acknowledgment: The authors thank Dr. Ponseti for his assistance and for allowing us to use his pictures of a clubfoot of a 3-day-old infant.

REFERENCES

1. Bensahel H, Guillaume A, Czukonyi Z, et al. Results of physical therapy for idiopathic clubfoot: a long-term follow-up study. *J Pediatr Orthop* 1990;10:189–92.
2. Browne D. Talipes Equino Varus. *The Lancet* 1934;227:969–74.
3. Cahuzac JP, Baunin C, Luu S, et al. Assessment of hindfoot deformity by three-dimensional MRI in infant clubfoot. *J Bone Joint Surg Br* 1999;81:97–101.
4. Cooper DM, Dietz FR. Treatment of idiopathic clubfoot. A thirty-year follow-up. *J Bone Joint Surg Am* 1995;77:1477–89.
5. Hamel J, Becker W. Sonographic assessment of clubfoot deformity in young children. *J Pediatr Orthop Pt B* 1996;5:279–86.
6. Hueter C. Klinik der Gelenkkrankheiten. Leipzig: Verlag Von F. C. W. Vogel, 1877.
7. Kite JH. Nonoperative treatment of congenital clubfoot. *Clin Orthop Red Res* 1972;84:29–38.
8. McKay D. New concept of and approach to clubfoot treatment: Section II-correction of the clubfoot. *J Pediatr Orthop* 1983;3:10–21.
9. O'Connor PJ, Bos CF, Bloem JL. Tarsal navicular relations in clubfoot: is there a role for magnetic resonance imaging? *Skeletal Radiol* 1998;27:440–4.
10. Ponseti IV. *Congenital clubfoot: fundamentals of treatment.* Oxford: Oxford Medical Publications, 1996.
11. Song HR, Carroll NC, Neyt J, et al. Clubfoot analysis with three-dimensional foot models. *J Pediatr Orthop P B* 1999;2:5–11.
12. Spero CR, Simon GS, Tornetta P 3d. Clubfeet and tarsal coalition. *J Pediatr Orthop* 1994;14:372–6.
13. Volkmann, R. v. Chirurgische Erfahrungen über Knochenverbiegungen und Knochenwahstum. *Virchows Arch Path Anat* 1862;24:152.
14. Wang C, Petursdottir S, Leifsdottir I, et al. MRI multiplanar reconstruction in the assessment of congenital talipes equinovarus. *Pediatr Radiol* 1999;2:262–7.
15. Wolff J. *Gesetz der Transformation der Knochen.* Berlin: Aug. Hirschwald, 1802.

Not all pages were attached

Journal of Pediatric Orthopaedics
20:699–700 © 2000 Lippincott Williams & Wilkins, Inc., Philadelphia

Chart Control
MS 361

Editorial

Clubfoot Management

No major congenital musculoskeletal deformity is easier to diagnose or simpler to treat than the clubfoot. And yet, the nature of the clubfoot deformity and its treatment continue to elude many orthopaedists despite the several available studies correcting misconceptions on this subject.

Sonographic examinations of fetus in uterus have revealed that most clubfeet develop in otherwise normal children toward the middle of pregnancy. Some transient muscular and collagen dysfunction localized in the posterior and medial aspects of the foot and leg appear to induce the deformity in a normally developed foot (11). The presence of vimentin and myofibroblast-like cells in the thick, tight, and shortened medial and posterior tarsal ligaments seems to play an important role in the pathogenesis and relapses of the clubfoot deformity (12). Some shortening and fibrosis are also observed in the gastrocsoleus and its tendon as well as in the posterior tibial muscle and its tendon (11).

These ligaments and tendons firmly hold the foot in equinus and the navicular, cuboid, and calcaneus in severe adduction and inversion. This causes the heel varus and the foot supination. The resistance of these ligaments to stretching varies greatly. Regardless of the degree of the deformity, many yield readily to manipulations, whereas others are harder to stretch and some even retract after being stretched. The ligaments in the forefoot are normal. Although adducted, the forefoot is not as supinated as the hindfoot. This causes the cavus (11).

In the past 40 years, the manipulative treatment of the clubfoot deformity has been largely supplanted by surgical interventions owing to the lack of understanding of the functional anatomy of the clubfoot. Even Kite (7), who understood how to correct the cavus and avoid foot pronation, did not realize that the calcaneus must abduct under the talus to evert, as was explained by Farabeuf (5) more than a century ago. In fact, pressure over the lateral aspect of the calcaneocuboid joint prevents the calcaneus from abducting and hence the heel varus from correcting (11).

At present, many surgeons consider nonoperative measures as preliminary steps to facilitate the primarily surgical interventions needed to correct the clubfoot toward 6 months of age (14). Improved surgical techniques have yielded better short-term results (4,15), but at what cost? Extensive surgical approaches and dissections with severance of most tarsal joint capsules and ligaments have become the fashion. Coleman (2) voices his concern about "the tremendous impact in the older child" that these operations may have. The consequences of ligament and joint damage inflicted by the extensive tarsal joint releases routinely performed in an effort to align the bones of a clubfoot should not be ignored.

Generally, children can walk without pain on poorly corrected or even uncorrected clubfeet. The pain, stiffness, weakness, and crippling disabilities in operated clubfeet usually appear in adulthood. Unfortunately, long-term results of surgery beyond adolescence are lacking.

Recently, nonsurgical techniques are being favored by a number of orthopaedists. Bensahel et al. (1) and others (4a,12a) in France treat clubfeet by well-trained physiotherapists with manipulative stretchings followed by taping of the leg and foot to a splint. Physiotherapy softens the tissues making the foot more compliant. However, repeated mobilization of the displaced tarsal joints will not help reshape them as immobilization in the proper position does. The French treatment is very lengthy, expensive, and fails to correct the deformity in more than one fourth of the cases.

Fifty years ago, after careful study of the pathological anatomy and the biomechanics of the tarsal joints, dissections of clubfeet of stillborn babies, and examination of serial histological sections of fetuses, I developed a technique of manipulations followed by plaster cast applications that have yielded excellent results in a majority of cases (8,11). In a 25–42 year follow-up review of my patients treated in the 1950s and 1960s, it was found that, although the treated clubfeet were less supple than the normal feet, there were no significant differences in function or performance compared to a population of the same age born with normal feet (3,10).

The heel varus and foot supination occur primarily in the tarsus. The tarsal joints are mechanically interrelated (6). Therefore, the components of the clubfoot deformity must be corrected simultaneously except for the equinus, which takes place in the ankle joint and must be corrected last. The cavus corrects as the foot is abducted with the forefoot in supination. The correction of the cavus brings the forefoot and the hindfoot into the proper alignment. The adduction is corrected when the foot in supination is abducted while counterpressure is applied with the thumb against the lateral aspect of the head of the talus, not the calcaneus.

Gradually, the lateral aspect of the head of the talus becomes covered by the navicular. As the foot is further abducted, the supination decreases. The foot should never be pronated, as explained below. When fully abducted the foot is plantigrade (5,11). As the calcaneus abducts together with the cuboid, it simultaneously everts owing to the curvature profiles of the subtalar joint, thereby correcting the heel varus. This method of

Iowa Ortho. Journal
Vol. 20
2000

TREATMENT OF IDIOPATHIC CLUBFOOT: AN HISTORICAL REVIEW

Matthew B. Dobbs, M.D.
José A. Morcuende, M.D., Ph.D.
Christina A. Gurnett, M.D., Ph.D.*
Ignacio V. Ponseti, M.D.

ABSTRACT

Idiopathic clubfoot, one of the most common problems in pediatric orthopaedics, is characterized by a complex three-dimensional deformity of the foot. The treatment of clubfoot is controversial and continues to be one of the biggest challenges in pediatric orthopaedics. This controversy is due in part to the difficulty in measuring and evaluating the effectiveness of different treatment methods. We believe the heart of the debate is a lack of understanding of the functional anatomy of the deformity, the biological response of young connective tissue to injury and repair, and their combined effect on the long-term treatment outcomes. The aim of this review is not only to assess the different methods of clubfoot treatment used over the years in light of an evolving understanding of the pathoanatomy of the deformity, but to also clarify factors that allow a safe, logical approach to clubfoot management. Further research will be needed to fully understand the pathogenesis of clubfoot, as well as the long-term results and quality of life for the treated foot.

Initial Period of Serial Manipulations and Immobilization

Idiopathic clubfoot is one of the most commonly referred problems in pediatric orthopaedics and is characterized by a complex three-dimensional deformity. When clubfoot is analyzed from an historical perspective, it is difficult to ascertain if other types of foot deformity, for example equinovarus or metatarsus adductus, were included in the definition. However, we believe most experienced authors were able to differentiate it from the other foot deformities when they referred to a clubfoot, given the natural history of no improvement without treatment.

*Department of Orthopaedic Surgery and Department of Pediatrics, University of Iowa, Iowa City, IA

Correspondence to :
Matthew B. Dobbs, MD, Department of Orthopaedic Surgery, University of Iowa Health Care, Iowa City, IA 52242
Telephone (319) 356-1616
e-mail: matthew-dobbs@uiowa.edu

Clubfoot was first depicted in ancient Egyptian tomb paintings, and treatment was described in India as early as 1000 B.C. The first written description of clubfoot was given to us by Hippocrates (circa 400 B.C.), who believed the causative factor to be mechanical pressure. He described methods for manipulative correction remarkably similar to current non-operative methods. Hippocrates understood two important principles in the treatment of clubfoot which succeeding generations have time and time again claimed as their own. He explained that the vast majority of cases can be successfully treated with serial manipulations, and that treatment should begin as early as possible before the deformity of the bones is well established. He also understood the inadequacy of restoring the foot to its normal position, but that it must be overcorrected and then held in this position afterwards to prevent recurrence.

Hippocrates treated clubfoot as soon after birth as possible. His technique involved repeated manipulations of the involved foot with his hands, followed by the application of strong bandages to maintain correction. There is no written account of the specifics of the actual manipulations, but there is mention of the importance of gentleness in correcting the deformity. When correction had been obtained by this method, special shoes were worn to maintain the correction and prevent recurrent deformity.

These techniques were apparently forgotten by subsequent generations. In the Middle Ages, the management of clubfoot and other deformities was the province of barber-surgeons, charlatans, and bonesetters, and minimal information is available concerning their practice. The next description of repeated stretching comes from Arcaeus, who in 1658 wrote a chapter on the treatment of clubfoot where he describes his stretching technique as well as two mechanical devices for maintaining the correction. The latter of these devices is similar to Scarpa's shoe, which will be discussed later.

In the mid 18th century, Cheselden, at St. Thomas' Hospital, treated clubfeet by repeated stretching using tape to maintain the improved position. From this time until 1803, when Scarpa published his historical *Memoir on Congenital Club-foot of Children,* the subject was apparently neglected.[17] The *Memoir* provides us with a description of his concept of the deformity. He considered the talus to be normal both in position and shape, and that the deformity was due to a dislocation of the forefoot inward upon the head of the talus. His treatment involved forceful manipulation, not gentle stretching, and application of a complicated mechanical device, later known as Scarpa's shoe. His treatment method was never successful in other hands and for that reason was not widely accepted.

In the year 1806, Timothy Sheldrake published an essay entitled *Distortions of the Legs and Feet of Children*.[18] Sheldrake used bandages like Hippocrates, and claimed that most of his patients could be cured in two to three months. He also recognized that although an infant's foot might be cured, it should not be left free until the child was able to walk. He believed that half the disability was due to the ligaments and the other half to the muscles. In expressing an opinion as to the possibility of a cure, he said "that children taken at or within two months of birth a cure will be in every sense complete by the time they begin to walk. But the older the child is when treatment is begun so much longer will it be before a cure can be effected."[18]

Introduction of Percutaneous Achilles Tenotomy

In 1823, Delpech performed subcutaneous tenotomy of the Achilles tendon in two patients with acquired talipes equinovarus. Sepsis occurred in both patients and he did not repeat the operation. The high incidence of infection discouraged most surgeons from performing tenotomies. However, Stromeyer continued to practice the operation. In 1831, he subcutaneously divided the tendo-Achillis in several patients with no fever or other signs of infection. W.J. Little was a young British surgeon who acquired an equinovarus deformity due to poliomyelitis. He visited Stromeyer in Hanover, who successfully operated on him. In addition, Stromeyer taught Little how to perform the procedure and allowed Little to operate on several of the patients who came to his clinic. Little then returned to England where he introduced this procedure with great success. In his treatise, Little argues strongly against the mechanical theory of this deformity.[13] His view was that the deformity was due to abnormal muscular contractions during intra-uterine development. This was in contrast to Stromeyer, who believed the deformity was due to a deficiency of the internal malleolus.

Little also pointed out that although the medial ligaments cannot directly produce the deformity, stretching them can result in improvement. He believed that associated with the distortion of the foot there was a rotation of the thigh outwards, consequently affecting the entire extremity. From this line of thought arose the use of irons extending from the foot to the pelvis in the treatment of clubfoot.

For thirteen years after Little recorded his success with subcutaneous tenotomy, no work of note appeared in the literature. Subcutaneous tenotomy enabled many feet considered beyond correction to be remarkably improved. Rogers in 1834 and Dickson in 1835[6] were the first to perform subcutaneous tenotomy for clubfoot in the United States. In 1866, Adams was the first surgeon to draw attention to the error of dividing the Achilles tendon as the first stage in the correction of the deformity.

In order to further understand clubfoot deformity, Adams performed dissections on several stillborn infants with clubfoot and reported the results.[1] This report is especially interesting because it is the first to describe microscopic examination of the muscles in a patient with clubfeet. He found that they did not exhibit any abnormal structural conditions either to the naked eye or microscopically. He also examined the bones of several specimens and discovered the only one that exhibited any marked change was the talus, which tilted medially. He believed the alteration in the contour of the talus resulted from the altered position of the calcaneus and navicular. His observations of the articular surfaces of the tarsal bones in these specimens further supported this notion.

After discussing the evidence for and against the various theories of the causation of clubfoot, Adams stated he believed the muscles were the deforming force, and that anatomically, clubfoot is a dislocation of the talocalcaneonavicular joint. He emphasized that the talus can only assume its normal shape and position after the dislocation between it and the navicular and calcaneus has been reduced. He recommended early surgery to obtain anatomical reduction of the dislocation.

Adams condemned the use of Scarpa's shoe or other existing mechanical devices. He believed Scarpa's shoe was not constructed in accordance with the deformity it was supposed to correct. He did agree with Scarpa on the importance of correcting the varus element of the deformity before the equinus. However, after condemning the use of mechanical devices, he devised his own straight splint of turned sheet metal applied along the outer side of the leg.

In 1838, M. Guerin described the use of plaster-of-Paris in the treatment of congenital clubfoot, and was apparently the first to use it for this purpose. We will later discuss in further detail the current use of plaster cast techniques for the correction of clubfoot.

Introduction of Aseptic Surgical Techniques, Anesthesia, and Radiographs

With the exception of tenotomies, the operative treatment of clubfoot began with the introduction of aseptic technique and anesthesia. In 1867, Lister introduced antiseptic principles of surgery. Esmarch in 1873 described a flat-rubber bandage for expressing blood from a limb. The introduction of the pneumatic tourniquet to limb surgery by Cushing in 1904 was invaluable.[5] The introduction of radiography made possible the precise evaluation of deformities. The advent of anesthesia completed the surgical renaissance, and these advances set the stage for orthopaedic surgery to evolve from a specialty with much empirical craftsmanship into an important scientific discipline. However, in the case of clubfoot treatment, this evolution also allowed the development of more radical operations aimed to obtain a "perfect" foot.

In 1891, Phelps not only divided the Achilles tendon, but carried out a medial release of all soft tissues, elongation of the tibialis posterior and division of the medial ligament of the ankle joint and plantar fascia, abductor hallucis, flexor hallucis longus, all the short flexors and finally performed osteotomy of the neck of the talus and wedge resection of the calcaneus.[15] Duval (1890), Ogston (1902) and Lane (1893) all carried out similar radical procedures.

Elmslie (1920), however, considered these procedures too radical in their approach to the condition. He understood the resistance to correction to be largely due to the talonavicular capsule, the plantar fascia, the Achilles tendon, and less importantly the posterior tibial tendon.[8] Ober (1920) also agreed with Elmslie's approach.

Brockman (1930), in addition to releasing the medial ligaments and plantar fascia, divided the abductor hallucis, tibialis posterior and subsequently carried out elongation of the Achilles tendon to correct the equinus.[3] He noticed that the operated feet were left stiff and immobile and he eventually abandoned this procedure. He argued that widespread soft tissue release lead to the formation of extensive fibrous tissue. Steindler reported good results with this technique in only 45% of 91 operations.[19]

Elmslie, Ober, and Brockman all emphasized the importance of immobilization in a plaster-of-Paris cast until correction was established. These authors' operations all pursue the same end, namely correction of the adduction and inversion due to the soft tissue contracture. The Brockman operation is the most complete. These corrective procedures are all based on the notion that all elements of clubfoot must be corrected before correction of equinus is undertaken.

Tendon transfers first became popular in the 1920's. Dunn in 1922 described transfer of the tibialis anterior tendon in selected cases of clubfoot to prevent relapse.[7] However, he did not publish his results. In 1947, Garceau and Manning reported good results in a series of tibialis anterior transfer in 83% of 86 patients with recurrent deformity. Barr (1958) believed that the tibialis anterior tendon should not be transferred to a lateral insertion if peroneus longus is functioning, due to resultant muscle imbalance.[2]

During the same time period that many soft tissue surgeries were being performed, many surgical procedures on the skeleton of the foot were also being devised for treatment of clubfoot. Operations aimed at correction of the prominent talus were popular during the latter part of the nineteenth century. In 1872, Lund performed talectomy, not as a corrective procedure for the equinovarus deformity, but because it was prominent.[14] Unfortunately, this procedure resulted in a plantigrade foot. Agustoni in 1888 and Morestin in 1901 also attempted to improve the position of the foot through talectomy. Steindler reported good results in 1950 with removal of the ossific nucleus of all the tarsal bones.

Osteotomy and wedge resection of the tarsal bones was performed by Robert Jones in 1908.[11] He always obtained as much correction as possible by manipulation and plaster before considering any operation on bone, and when necessary, removed as little bone as possible. Dénis Browne in 1937 disagreed and suggested that in all cases beyond the possibility of correction by casting, a "cresentic resection of the tarsus " below and in front of the ankle should be performed right away.[4] However, as Robert Jones wisely said in 1920, "There is not much to be said for the removal of large masses of bone. I have never seen a case of clubfoot when a good portion of bone has been removed where the foot has functioned well."[11] In fact there are very few indications for surgery on the bones of the foot to correct clubfoot deformity.

Interestingly, current trends contend that clubfoot is a surgical deformity where only mild cases can be corrected by manipulation and immobilization. This view is supported by the disappointing results obtained after prolonged manipulations and casting in the more severe cases. Interestingly, most publications on the surgical treatment of clubfoot emphasize that early alignment of the displaced skeletal elements results in normal anatomy of bones, joints, ligaments and muscles. However, there is still no unanimity about when surgery should be performed, how extensive it should be, or how to evaluate the results. Adding to the uncertainty is the lack of long-term follow-up of surgically treated cases.

We believe this lack of understanding has resulted in poor correction of the initial deformity accompanied by severe iatrogenic deformities. An immediate correction of the anatomic position of the displaced bones is, in fact, impossible. Any attempt to roughly realign the talonavicular, talocalcaneal, and calcaneocuboid joints requires wire fixation through the joint cartilage. Inevitably, the joint cartilage, as well as the joint capsules, are damaged and joint stiffness sets in. A few reports indicate that surgery is almost invariably followed by deep scarring, which appears to be particularly severe in infants. In addition, the average failure rate of clubfoot surgery is 25% (range 13% to 50%) and many complications can occur including wound problems, persistent forefoot supination, loss of reduction and recurrence, overcorrection of the hindfoot, dorsal subluxation of the navicular, and loss of normal motion of the ankle and subtalar joints.

Return to Serial Manipulations and Immobilization

It is striking when reviewing the history of clubfoot management to see how the same mistakes are made time and time again by the treating physicians. The mistakes are made because the treating physician consistently ignores what has already been learned by his predecessors and instead he is often misguided by new information or trends.

Hugh Owen Thomas (1834-1891) studied medicine at Edinburgh and University College, London. He developed the Thomas test for hip flexion contracture as well as the Thomas splint used in fracture treatment. In addition, he developed the Thomas wrench, a device used to forcibly correct clubfoot. The plane through which the correction occurred was never clear. Experts claimed that if properly applied, the Thomas wrench could easily detach the foot from a cadaver.

In 1894, Sir Robert Jones at the British Orthopaedic Society said that he had given up operative treatment in place of treatment by manipulation. He wrote that he had never met with a case in which treatment had been started in the first week where deformity could not be corrected by manipulation and bracing for two months. He also noted that the cure was only finally completed when the patient could walk. He accepted the view that the condition is due to pure mechanical causes. He expressed the view that tenotomy should only very rarely be necessary. Bone operations, he held, should never be performed without obtaining maximum correction by manipulation with the Thomas wrench. However, his claimed results could not be duplicated.

Denis Browne (1892-1967), a second generation Australian, became the father of pediatric surgery in the United Kingdom. He is best known in orthopaedics for his Denis Browne bar used to correct clubfoot; a similar abduction orthosis is still used today to maintain correction of the deformity.

Michael Hoke (1874-1944) was the first medical director of the Scottish Rite Hospital in Decatur, Georgia, and was instrumental in advocating manipulative treatment for clubfoot and holding the correction with plaster casts.

Kite then became the leading advocate of the conservative treatment of clubfoot for many years in the early and mid 1900's. Kite completed his orthopaedic training at Johns Hopkins and succeeded Michael Hoke as medical director of the Scotish Rite Hospital in Decatur, Georgia. He continued the meticulous clubfoot cast application and molding that he had learned from Hoke. Kite corrected each component of the deformity separately instead of simultaneously. He was able to correct the cavus and to avoid foot pronation, but correcting the heel varus took many casts. He recomended "getting all the correction by abducting the foot at the midtarsal joint" with the thumb pressing "on the lateral side of the foot near the calcaneocuboid joint."[12] However, by abducting the forefoot against pressure at the calcaneocuboid joint the abduction of the calcaneus is blocked thereby interfering with the correction of the heel varus. Therefore, it took many months and cast changes to slowly correct the heel varus and obtain a plantigrade foot. Due to the inordinate amount of time it took to obtain correction of the deformity, he lost many followers who sought quicker corrections via surgery.

It was through his attempt to understand the pathophysiology of clubfoot, as well as his ability to learn from the mistakes of his predecessors, that Ponseti developed his current method of treatment for clubfoot. His understanding of the anatomy of the tarsus of the normal foot and of the clubfoot was greatly enhanced by the work of Farabeuf's *Precis de Manual Operatoire*, first published in 1872.[9] Farabeuf described how in the normal foot when the calcaneus rotates under the talus, it adducts, flexes, and inverts. More precisely, as the foot goes into varus, the calcaneus adducts and inverts under the talus while the cuboid and the navicular adduct and invert in front of the calcaneus and the talar head, respectively. Farabeuf also explained that in the clubfoot deformity the ossification center of the talus responds to the abnormal pressures placed on it by the displaced navicular. In addition, he observed that while bony deformities in the infant with clubfoot were reversible, recurrences are high due to soft tissue contractures. In his time, clubfoot patients were rarely treated at an early age, so surgery was usually necessary to correct the deformity.

Huson in 1961 wrote his Ph.D. thesis entitled "A functional and anatomical study of the tarsus."[10] This work supported and advanced the ideas of Farabeuf. Huson demonstrated that the tarsal joints do not move as single hinges but rotate about moving axes. Furthermore, motions of the tarsal joints occur simultaneously. If the motion of one of the joints is blocked, the others are functionally blocked as well. Based on these concepts, Ponseti developed his treatment guidelines:

1. All the components of the clubfoot deformity have to be corrected simultaneously with the exception of the equinus which should be corrected last.
2. The cavus results from a pronation of the forefoot in relation to the hindfoot, and is corrected as the foot is abducted by supinating the forefoot and thereby placing it in proper alignment with the midfoot.
3. While the whole foot is held in supination and in flexion, it can be gently and gradually abducted under the talus, and secured against rotation in the ankle mortise by applying counter-pressure with the thumb against the lateral aspect of the head of the talus.
4. The heel varus and foot supination will correct when the entire foot is fully abducted in maximum external rotation under the talus. The foot should never be everted.
5. After the above is accomplished, the equinus can be corrected by dorsiflexing the foot. The tendo-Achilles may need to be subcutaneously sectioned to facilitate this correction.

When proper treatment of clubfoot with manipulation and plaster casts has been started shortly after birth, a good clinical correction can be obtained in the vast majority of cases. A plaster cast is applied after each weekly session to retain the degree of correction and soften the ligaments. After two months of manipulation and casting the foot often appears slightly overcorrected. As mentioned, the percutaneous tenotomy of the Achilles tendon is an office procedure and is done in 85% of Ponseti's patients to correct the equinus deformity. Open lengthening of the tendo Achilles is indicated for children over one year of age. This is done under general anesthesia. Excessive lengthening of the tendon must be avoided since it may permanently weaken the gastrocsoleus. Transfer of the tibialis anterior tendon to the third cuneiform is done after the first or second relapse in children older than two-and-a-half years of age, when the tibialis anterior has a strong supinatory action. The relapsed clubfoot deformity must be well corrected with manipulations and two or three plaster casts left on for two weeks each before transfer of the tendon. With appropriate early manipulations and plaster casts, surgery of the ligaments and joints should only be rarely necessary.

To provide patients with a functional, pain-free, normal-looking foot, with good mobility, without calluses, and requiring no special shoes, and to obtain this in a cost-effective way, further research will be needed to fully understand the pathogenesis of clubfoot and the effects of treatment, not only in terms of foot correction, but also of long-term results and quality of life. One thing that is definitely missing in the literature is a long term follow up study on surgically treated clubfeet. The authors of this paper are currently involved in a multi-center retrospective study to look at this group of patients.

REFERENCES

1. **Adams, W.** Club-foot; its causes, pathology, and treatment. London:Churchill, 1866.
2. **Barr, J.S.** Tendon transplantation. *J Bone Joint Surg*, 40-B: 166, 1958.
3. **Brockman, E.P.** *Congenital Club-foot.* Bristol: Wright, 1930.
4. **Browne, D.** Modern methods of treatment of clubfoot. *Brit. Med. J.*, ii: 570, 1937.
5. **Cushing, H.** Pneumatic tourniquets, with special reference to their use in craniotomies. *Med. News.*, 84: 577, 1904.
6. **Dickson, R.** An essay on club-foot and some analogous distortions. N.Y. quart. *J. Med. Surg.*, 2:1, 1835.
7. **Dunn, N.** Stabilizing operations in the treatment of paralytic deformities of the foot. *Proc. Roy. Soc. Med.*, 15: 15, 1922.
8. **Elmslie, R.C.** The principles of treatment of congenital talipes equino-varus. *J. Orthop. Surg*, 2: 669, 1920.
9. **Farabeuf, L.H.** Precis de manual operative (4th ed.). Masson, Paris, 1893.
10. **Huson, A.** Een ontleedkundig functioneel Onderzoek van de Voetwortel (An anatomical and functional study of the tarsus). Ph.D. dissertation, Leiden University, 1961.
11. **Jones, R.** Discussion on the treatment of intractable talipes equino-varus. *Trans. Brit. Orthop. Soc.* 1: 20, 1895.
12. **Kite, J.H.** Non-operative treatment of congenital clubfeet; a review of one hundred cases. *South. Med. J.* 23: 337, 1930.
13. **Little, W.J.** *A treatise on the nature of club-foot and analagous distortions.* London: W. Jeffs, S. Highley, 1839.
14. **Lund, E.** Removal of both astragali in a case of severe double talipes. *Brit. Med. J.*, ii: 438, 1872
15. **Phelps, A.M.** The present status of the open incision method for talipes varo-equinus., *New Engl. Med. Mon.*, 10: 217, 1891.

16. **Ponseti, I.V.** *Congenital clubfoot: Fundamentals of Management.* Oxford Univ. Press, 1996.
17. **Scarpa, A.** *A memoir on the congenital club feet of children.* Translated from Italian by J.H. Wishart, 1818.
18. **Sheldrake, T.** *Distortions of the legs and feet in children.* 1806.
19. **Steindler, A.** Postgraduate lectures on orthopedic diagnosis and indications, Vol. 1. Springfield, Illinois: Thomas, 1950.

International Orthopaedics (SICOT) (1997) 21: 137–141

International
Orthopaedics

Current concepts

Common errors in the treatment of congenital clubfoot

I. V. Ponseti

Department of Orthopaedic Surgery, University of Iowa, Iowa City, Iowa 52242, USA

Accepted: 4 September 1996

Summary. *The conservative treatment of clubfeet in newborn babies is detailed, and the pitfalls in the treatment are commented.*

Résumé. *Le traitement conservateur des pieds bots à la naissance est expliqué en détail et les erreurs de traitement sont commentés.*

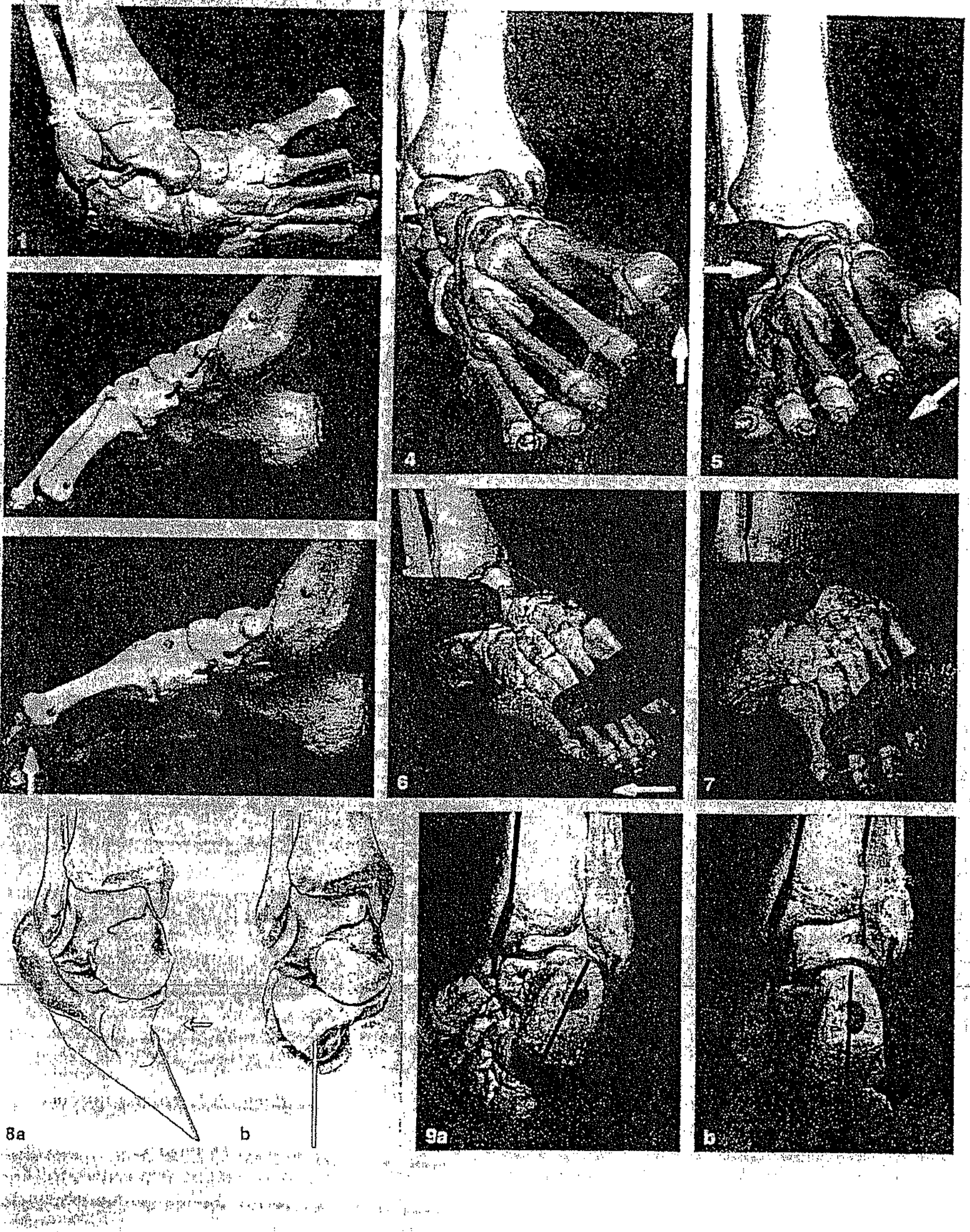
Most orthopaedic surgeons agree that the initial treatment of congenital club foot should be non-operative, beginning in the first days of life so as to take advantage of the favourable fibroelastic properties of the connective tissue which forms the ligaments, joint capsules and tendons. Early operation induces fibrosis, scarring and stiffness [4, 5]. It must be delayed until the child is at least three months old. These first three months offer the skilled and knowledgeable surgeon a golden opportunity to correct the deformity by manipulation and casting. Proper manipulative techniques followed by applications of well moulded plaster casts offer the best and safest correction of most clubfeet in infants [11].

Failures of manipulative treatment usually occur when the surgeon lacks a thorough knowledge of the kinematics and pathological anatomy of the deformity. The kinematics of clubfoot were clearly described by Farabeuf in 1892 [6] and Brockman in 1930 [2]. In 1963, when presenting our results of fifteen years of treatment, we explained that to correct the deformity all of the foot distal to the talus must be made to rotate laterally, i.e. abduct, underneath the talus which is fixed in the ankle mortice [10]. In a recent review of our patients treated 25 to 42 years ago [3], it was found that although the treated clubfeet were less supple than the normal foot, there were no significant difference in function or performance compared to a population of a similar age born with normal feet.

Our treatment is easy to learn. An interested resident is proficient in the technique after correcting two or three clubfeet. The main stages of the correction are illustrated in Figs. 1 to 9 using a facsimile of a clubfoot made of plastic bones and elastic strings.

First, the resident learns to identify by palpation the position of the main bones of the foot in relation to the malleoli and to the head of the talus. In the clubfoot the calcaneus, the navicular and the cuboid are rotated medially in relation to the talus, and are firmly held in adduction and inversion by very tight ligaments and tendons (Fig. 1). Although the whole foot is in extreme supination, the forefoot is pronated in relation to the hindfoot and this causes the cavus, the first metatarsal being in more plantar flexion than the lateral metatarsals (Fig. 2). The resident feels the distance between the medial malleolus and the tuberosity of the navicular. The shorter this distance the worse is the clubfoot (Fig. 1). When abducting the foot he must estimate the degree of resistance of the navicular to be moved away from the medial malleolus. This resistance correlates with the severity of the deformity.

Reprint requests to: I. V. Ponseti


1
2
3
4
5
6
7
8a
b
9a
b

To correct the clubfoot, the cavus is corrected first by supinating the forefoot and dorsiflexing the first metatarsal (Figs. 3, 4). The forefoot must never be pronated.

To correct the varus and adduction, the foot in supination is abducted while counterpressure is applied with the thumb against the head of the talus (Figs. 5, 6). The calcaneus abducts by rotating and sliding under the talus (Fig. 8). As the calcaneus abducts it simultaneously extends and everts, and thus the heel varus is corrected (Figs. 8, 9). The calcaneus cannot evert unless it is abducted [7]. The improvement obtained by manipulation is maintained by immobilising the foot in a plaster cast for five to seven days. With immobilisation, the tight medial and posterior tarsal ligaments tend to yield. The deformity can be gradually corrected with further manipulations and five or six changes of cast. To fully stretch the medial tarsal ligaments in the later casts, the foot in front of the talus must be severely abducted to an angle of about 60° (Fig. 7). The heel must not be touched.

Fig. 1. Model of a clubfoot made with plastic bones and elastic strings simulating the ligaments. The talus and calcaneus are in severe flexion. The calcaneus, navicular and the cuboid are adducted and inverted. The navicular tuberosity is close to the medial malleolus. The metatarsals are adducted

Fig. 2. Medial view. The first metatarsal is in more flexion than the other metatarsals, thus causing the cavus

Fig. 3. The cavus is corrected by extending the first metatarsal and supinating the forefoot

Fig. 4. Front view. To initiate the correction of the clubfoot the first metatarsal is extended and the forefoot is held in supination in proper alignment with the midfoot and the calcaneus. In this position the foot can be abducted under the talus

Fig. 5. Gradual correction is obtained by abducting the supinated foot with counterpressure applied on the lateral aspect of the head of the talus. The heel is not touched

Fig. 6. The flexed foot, lightly supinated, is slowly abducted while counterpressure on the head of the talus stabilizes the bone against rotation in the ankle mortice. The medial tarsal ligaments are stretched allowing the calcaneus to abduct with the foot and the anterior tuberosity of the calcaneus is disengaged from its position under the head of the talus

Fig. 7. Complete correction of the clubfoot requires severe abduction of the midfoot and forefoot to stretch the tight medial tarsal ligaments

Fig. 8 A In the clubfoot the calcaneus is severely adducted, flexed and inverted under the talus. B When the calcaneus abducts it simultaneously extends and everts to its normal and neutral position under the talus. (Fig. 8 originally appeared in [10])

Fig. 9 A Posterior view. The heel is in varus when the foot and calcaneus are adducted. B The heel is in the normal position when the adduction of the foot and of the calcaneus are corrected

The equinus is corrected by dorsiflexing the fully abducted foot. A tenotomy of the Achillis tendon is often necessary to completely correct the equinus [11].

Many degrees of severity and rigidity of clubfoot are found at birth. Failures in treatment are related more often to faulty techniques of manipulation and application of the cast than to the severity of the deformity. Our experience of 50 years indicates that most clubfeet, when treated shortly after birth, can be easily corrected by manipulation and five or six applications of plaster casts. A small number of infants with very severe, short, fat feet with stiff ligaments unyielding to stretching will need surgical correction. Long term function and the results of our patients treated in infancy indicate that the well treated clubfoot is not a handicap and is compatible with a normal active life [3].

The common errors in the treatment of the clubfoot and how to avoid them are:

1. *Pronation or eversion of the foot (Fig. 10).* The wrong assumption is made that the severe supination in the clubfoot will correct by pronating or everting the foot. Pronation of the foot will make the deformity worse by increasing the cavus and locking the adducted calcaneus under the talus, while the midfoot and forefoot are twisted into eversion [12]. Supination of the foot and heal varus are corrected by abducting the supinated foot under the talus.

2. *External rotation of the foot to correct abduction while the calcaneus is in varus.* This causes a posterior displacement of the lateral malleolus by externally rotating the talus in the ankle mortice. The posteriorly displaced lateral malleolus, seen in poorly treated clubfoot, is an iatrogenic deformity [12]. It does not occur when the foot is abducted in flexion and slight supination to stretch the medial tarsal ligaments, thus allowing the calcaneus to abduct under the talus with correction of the heel varus.

3. *Abducting the foot at the midtarsal joints with the thumb pressing on the lateral side of the foot near the calcaneocuboid joint, arching the foot as if straightening a bent wire.* This was taught by Kite and is a major error [8]. By abducting the foot against pressure at the calcaneocuboid joint the abduction of the calcaneus is blocked, thereby interfering with correction of the heel varus (Fig. 11). Kite wrongly believed that the heel varus would correct simply by everting the calcaneus. He did not realise that the calcaneus can evert only when it is abducted, i.e. laterally rotated, under the talus. This error in the Kite technique had a major neg-

Fig. 10 Pronation of the forefoot will not correct the supination and adduction of the midfoot and of the calcaneus. The calcaneus will remain locked in adduction under the talus and the midfoot and forefoot will be twisted into eversion leading to increased cavus and to a "bean-shaped foot" deformity

Fig. 11. Arching the foot as if to straighten a bent wire with pressure applied on the lateral side of the foot near the calcaneocuboid joint is a major error because medial pressure at the calcaneocuboid joint prevents the calcaneus from abducting and therefore from everting, since the calcaneus can evert only when it is abducted

ative impact on the manipulative treatment of clubfoot, Kite was able to correct the deformity after many manipulations and changes of cast. His less patient followers, with some notable exceptions, have resorted to surgery.

4. *Frequent manipulations not followed by immobilisation.* The foot should be immobilised with the contracted ligaments at the maximum stretch obtained after each manipulation. Plaster casts applied between manipulations serve to keep the ligaments stretched, and to loosen them sufficiently to facilitate further stretching in the manipulations following at intervals of five to seven days [11].

5. *Application of below knee instead of toe to groin casts.* The longer plasters are needed to prevent the ankle and talus from rotating. Since the foot must be held in abduction under the talus, the talus must not rotate, otherwise the correction obtained by manipulation is lost.

6. Attempts to correct the equinus before the heel varus and foot supination are corrected will result in a rocker bottom deformity.

7. *Failure to use shoes attached to a bar in external rotation for three months full-time and at night for two to four years.* These splints are necessary to counter the tendency of the ligaments to tighten, causing relapses [11].

8. *Attempts to obtain a perfect anatomical correction.* It is wrong to assume that early alignment of the displaced skeletal elements results in a normal anatomy and good long term function of the clubfoot. We found no correlation between the radiographic appearance of the foot and long-term function [3]. In severe clubfoot, complete reduction of the extreme medial displacement of the navicular may not be possible by manipulation. The medial tarsal ligaments cannot be stretched sufficiently to properly position the navicular in front of the head of the talus. Since the joint capsules and ligaments play a crucial role in the kinematics of the tarsal joints [7], they cannot be stripped away with impunity. In infants, the medial ligaments should be gradually stretched as much as they will yield rather than cut, regardless of whether a perfect anatomical reduction is obtained or not [11].

With a partially reduced navicular, the forefoot can be brought into proper alignment with the hindfoot because the ligaments in front of the navicular and the bifurcate ligaments will yield, allowing lateral displacement and lateral angulation of the cuneiforms and of the cuboid with proper positioning of the metatarsals. The calcaneus can be abducted sufficiently to bring the heel into a normal neutral position. This anatomically imperfect correction will provide good functional and cosmetic results for at least four decades, avoiding many of the complications of operative tarsal release. However, in children more than four or five months old, the ligaments become stiffer and they may need to be divided surgically to adequately position the foot.

Relapses are common in severe clubfeet and are probably caused by the same pathology that initiated the deformity, but they may easily be corrected by manipulation and two to three plaster casts. When a second relapse occurs and the tibialis anterior muscle has a strong supinatory action, the tendon must be transferred to the third cuneiform. This transfer prevents further relapse and corrects the anteroposterior talcocalcaneal angle, thereby greatly reducing the need for tarsal release [9, 10].

Surgeons with limited experience in the treatment of clubfoot should not attempt to correct the deformity with manipulation and plaster casts. They may succeed in correcting mild clubfeet, but the severe cases require experienced hands. It is easy to compound the deformity, making further treatment difficult or impossible. No more than two or three changes of cast should be undertaken if correction is not being achieved. Referral to a centre with expertise in the management of clubfoot should then be made so that more skilled attempts at manipulation can be attempted before tarsal release operation is considered. The functional results are always better if this type of surgery can be avoided [1].

References

1. Aronson J, Puskarich ChL (1990) Deformity and disability from treated clubfoot. J Pediatr Orthop 10: 109
2. Brockman FP (1930) Congenital club foot. John Wright, Bristol, and Simpkin Marshall, London
3. Cooper DM, Dietz FR (1995) Treatment of idiopathic clubfoot. A thirty year follow-up. J Bone Joint Surg [Am] 787: 1477
4. Dimeglio A (1977) Le traitement chirurgical du pied bot varus equin. Encyclopedie medico chirurgicale. Tome Techniques Chirurgicales, Paris
5. Epeldegui T (1993) Conceptos Y controversias sobre el pie zambo. Vincente ed, Madrid
6. Farabeuf LH (1893) Precis de manual operative, 4th edn. Masson, Paris. (First published 1872, Masson, Paris).
7. Huson A (1991) Functional anatomy of the foot. In: Jahss JH (ed) Disorders of the foot and ankle, 2nd edn, vol 1. Saunders, Philadelphia
8. Kite JH (1964) The clubfoot. Grune & Stratton, New York London
9. Laaveg SJ, Ponseti IV (1980) Long term results of treatment of congenital clubfoot. J Bone Joint Surg [Am] 62: 23
10. Ponseti IV, Smoley EN (1963) Congenital club foot: the results of treatment. J Bone Joint Surg [Am] 45: 261
11. Ponseti IV (1996) Congenital clubfoot. Fundamentals of treatment. Oxford University Press, Oxford, New York
12. Swann M, Lloyd-Roberts GC, Catterall A (1969) The anatomy of uncorrected clubfeet. A study of rotation deformity. J Bone Joint Surg [Br] 51: 263

Treatment of Idiopathic Clubfoot

A Thirty-Year Follow-up Note*†

BY DOUGLAS M. COOPER, M.D.‡, AND FREDERICK R. DIETZ, M.D.§, IOWA CITY, IOWA

Investigation performed at the Department of Orthopaedic Surgery, University of Iowa Hospitals and Clinics, Iowa City

ABSTRACT: We evaluated forty-five patients who had seventy-one congenital clubfeet. The average age was thirty-four years (range, twenty-five to forty-two years). Twenty-nine of these patients had been evaluated and reported on in 1980. We performed pedobarographic and electrogoniometric analyses in addition to the clinical and radiographic studies performed previously. With the use of pain and functional limitation as the outcome criteria, thirty-five (78 per cent) of the forty-five patients had an excellent or good outcome compared with eighty-two (85 per cent) of ninety-seven individuals who did not have congenital deformity of the foot.

The patient's occupation, passive dorsiflexion as measured with a hand-held goniometer, the anteroposterior calcaneus-fifth metatarsal angle, the total foot pressure time integral, and the number of rapid single-limb toe-ups that could be performed were the only variables that differed significantly between the feet that had an excellent or good result and those that had a poor result ($p < 0.05$). A comparison of the feet that had an excellent or good outcome with those that had a poor outcome with regard to body-mass index, peak pressure under the heel, and force time integral under the metatarsal heads revealed a p value that was between 0.05 and 0.08 for each variable.

The technique of treatment led to good long-term results in our patients who had clubfoot. The data suggest that a sedentary occupation and avoidance of excessive weight gain may improve the over-all long-term result. Excessive weakening of the triceps surae may predispose patients to a poor result; therefore, it is prudent to avoid overlengthening of this muscle. The outcome could not be predicted from the radiographic result.

The determination of the optimum treatment for idiopathic clubfoot has been hampered by the lack of long-term follow-up studies. Studies with short-term follow-up that rely on radiographic findings or the range of motion for the assessment of outcome may not reflect accurately the factors necessary for good lifelong function of the foot. In the present study, we assessed the results in a group of adults who had been managed with a single treatment program at the University of Iowa Hospitals and Clinics under the direction of Dr. Ignacio Ponseti. Our initial hypothesis was that a combination of good muscle strength, well balanced pressure distribution under the sole of the foot (as assessed with a pedobarograph), and greater ankle-foot mobility (as assessed with an electrogoniometer) would correlate with less pain in the foot and better function.

Materials and Methods

One hundred and twenty-six patients with clubfoot who had been treated at our hospital between 1950 and 1967 met the inclusion criteria for this study. None of the patients had any other congenital anomaly, all had been less than four months old when first seen, and all either had had no previous treatment aside from use of a splint or had had fewer than three plaster casts applied before being seen by us. We were able to contact sixty-one of these patients by mail or telephone, and we invited them to participate in the study. Four patients refused, and twelve who were willing to participate were not evaluated because of time or financial constraints or because they lived too far from our hospital. Nine of the twelve patients who were willing but unable to participate in the study returned our letter. Seven stated that the feet were doing well, and two stated that the feet were doing poorly. These nine patients were not included in the data analysis or outcomes. The remaining forty-five patients (thirty-four men and eleven women), who had seventy-one clubfeet, composed the study group. Twenty-six (58 per cent) of them had bilateral clubfoot and nineteen (42 per cent) had unilateral clubfoot, with nine right and ten left feet affected. Twenty-nine of the forty-five patients had been included in the 1980 study by Laaveg and Ponseti.

All of the patients completed a questionnaire, were examined radiographically, and had a complete physical examination performed by one or both of us at the University of Iowa Hospitals and Clinics. Complete electrogoniometric measurements were available for thirty-nine patients. Thirty-four patients were evaluated with a pedobarograph. The patients who were not evaluated with these modalities were seen during periods when the equipment was not available.

*No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article. No funds were received in support of this study.

†Read in part at the EMED User Meeting, Ulm, Germany, 1994. Awarded Second Prize by Novel, GMBH, Munich, Germany.

‡312 East Main Street, Marshalltown, Iowa 50158.

§Department of Orthopaedic Surgery, University of Iowa Hospitals and Clinics, 1012 Roy Carver Pavilion, Iowa City, Iowa 52242.

To better assess the quality of the results of the treatment regimen, we compared the pain and function of the foot in the patients with those in a group of individuals who did not have congenital deformity of the foot. We attempted to determine findings that were associated with an excellent or good outcome as opposed to a poor outcome. Demographic data (such as the sex and occupation of the patient), radiographic measurements, mobility of the foot (as measured with a hand-held goniometer and a two-dimensional electrogoniometer [Ankle-Foot Elgon; Therapeutics Unlimited, Iowa City, Iowa]), pressure distribution under the sole of the foot (as measured with a pedobarograph [EMED-SF; Novel, GMBH, Munich, Germany]), muscle strength, and residual deformity were assessed with respect to the excellent or good outcomes and the poor outcomes.

Treatment Regimen

Our treatment regimen for clubfoot involves gentle manipulation and the application of serial casts without the use of anesthesia. The first cast is applied as soon as possible after birth, with the manipulation repeated and a new cast applied at five to seven-day intervals. An average of seven, eight, or nine casts are applied before complete correction is obtained. If the equinus deformity remains uncorrected, the Achilles tendon is sectioned percutaneously with the use of local anesthesia before the application of the last cast, which is usually worn for three weeks. The patient then wears a Denis Browne splint full time for two or three months and is weaned to nighttime use, which continues for two to six years. A key feature of the manipulation that allows rapid correction is the reduction of the cavus deformity with the initial casts. By reducing the cavus deformity first, the joints of the midfoot are realigned so that rapid correction of the adductus and varus deformity of the heel occurs with progressive abduction of the forefoot while the head of the talus is used as a fulcrum[11]. A relapse is usually treated with repeat manipulation and application of a cast, which is worn for four to eight weeks. A formal lengthening of the Achilles tendon may be necessary at this time. In patients who are two and one-half years old or more, the anterior tibial tendon is transferred to the third cuneiform bone if this tendon causes supination of the foot during dorsiflexion.

Questionnaire

Each patient completed a questionnaire with information regarding occupation, education, pain, function, satisfaction with the treatment, and additional treatment received outside of our hospital. Occupations were divided into low-foot-demand and high-foot-demand categories on the basis of our assessment of the amount of prolonged standing or walking, or both, that was required and whether the occupation permitted the patient to stop bearing weight on the foot at hi her discretion. High-foot-demand occupations inc day laborer, janitor, busing tables, and cook. Low-f demand occupations include accountant, office n ager, sales manager, homemaker, and secretary.

Physical Examination

The physical examination included assessmen the height and weight of the patient, limb length (n sured from the anterior superior iliac spine to the dial malleolus), circumference of the calf, and ler and width of the feet. The body-mass index was de mined by division of the weight in kilograms by square of the height in meters. We inspected the feet evidence of calluses and palpated them for areas tenderness. The function of the anterior tibial mus was recorded. Gait was analyzed with respect to limp or back-kneeing as well as the ability to walk on heels or toes and to hop. We estimated varus or val deformity of the heel, adduction or abduction of forefoot, and the presence of cavus with the pati standing and the examiner using a hand-held gonio eter. We also measured passive dorsiflexion, plan flexion, varus and valgus deformity of the heel, supi tion, pronation, adduction, and abduction with a har held goniometer. Motor strength of the anterior tibia posterior tibialis, gastrocnemius-soleus, peroneals, tensor hallucis longus, extensor digitorum commur flexor hallucis longus, and flexor digitorum longus w graded on a scale of 0 to 5. Grade 5 indicated n mal strength, trace weakness indicated that the musc was less strong than the muscle on the contralate side but was still grade 5, grade 4 indicated mov ment against resistance, grade 3 indicated moveme against gravity, grade 2 indicated movement with gra ity eliminated, grade 1 indicated palpable contracti of the muscle only, and grade 0 indicated no contra tion. The patient stood on one foot and perform rapid toe-ups, stopping when he or she had done for of them or when there was moderate pain or fatigue the gastrocnemius-soleus.

Radiography

Anteroposterior and lateral radiographs of the fe were made with the patient standing, and oblique r diographs were made with the patient sitting. On th anteroposterior radiographs, we measured the tal calcaneal angle, the angle between the calcaneus ar the fifth metatarsal, and the angle between the tal and the first metatarsal. On the lateral radiographs, w measured the talocalcaneal angle (with the method Vanderwilde et al.), the angle between the talus an the first metatarsal, the angle between the calcane and the first metatarsal, and the angle between the fir and fifth metatarsals. We then calculated the taloca caneal index as the sum of the anteroposterior and la eral talocalcaneal angles. We also recorded any wedgin

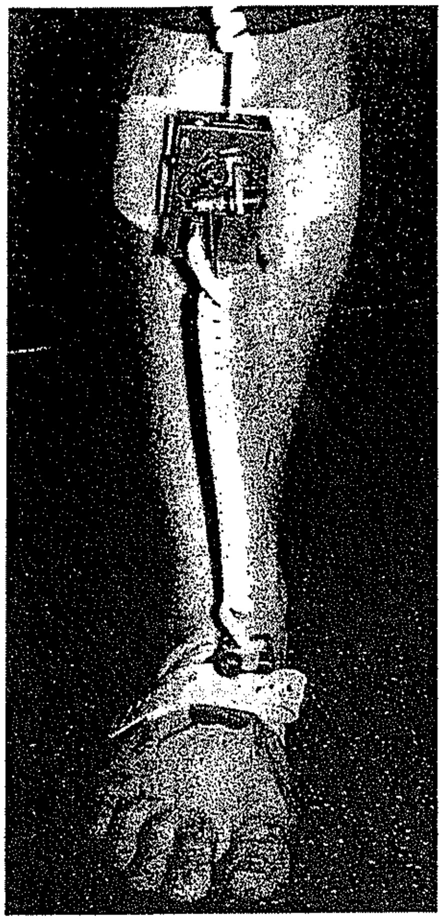


FIG. 1

Photograph of the electrogoniometer in place. The tibial attachment piece is contoured to fit on the crest of the tibia to minimize motion and is secured by a Velcro strap. The footpiece is attached by placement of a thin foam pad, which is sticky on both surfaces, between the flat metal plate and the foot and is secured by a rubber strap. A long, flexible telephone cord runs from the device to the recorder; the cord permits walking with the device in place.

of the navicular bone or flattening of the trochlea of the talus and graded these changes as none, mild, moderate, or severe[13]. Degenerative changes at the ankle, subtalar, talonavicular, calcaneocuboid, navicular-cuneiform, and Lisfranc joints, as evidenced by osteophytes, narrowing of the joint space, cysts, or subchondral sclerosis, were recorded as well. The previous radiographs of the twenty-nine patients who had been reported on previously[7] were compared with the most recent radiographs for evidence of progressive degenerative osteoarthrosis.

Electrogoniometric Analysis

We examined the feet using a lightweight, adjustable ankle-foot electrogoniometer, with the leads placed on the anterior aspect of the proximal end of the tibia and on the navicular or second metatarsal (Fig. 1). This electrogoniometer uses four high-precision potentiometers to measure motion of the foot and ankle. The potentiometers are arranged in pairs at each end of a lightweight telescoping rod. One pair of potentiometers measures rotation of the foot and ankle in the frontal plane (inversion and eversion) and the other pair measures rotation in the sagittal plane (dorsiflexion and plantar flexion). Axial rotations occur within the telescoping rod so that they do not introduce artefact into the measurement of the other two planes. We measured dorsiflexion, plantar flexion, eversion, and inversion with use of a reference starting point with the patient standing stationary and the feet shoulder-width apart. With one lead fixed to the tibia, any motion in the lead attached to the foot was recorded on graph paper and was later translated into degrees. Measurements were made during a single step of normal walking, during the passive range of motion with the patient sitting and the leg and foot hanging free, and during the active range of motion with the patient sitting. To determine the over-all suppleness of the foot, we used a digitizer and measured the area (in square centimeters) inside the passive range-of-motion circle (Fig. 2).

Pedobarographic Analysis

The patient was asked to walk on the pedobarograph, which operates with individually calibrated capacitive pressure sensors. The sensor platform has a sensor area of 445 by 225 millimeters, with a local resolution of two sensors per square centimeter, a recording frequency of seventy hertz, and a measurement range of one to 127 newtons per square centimeter. The patient was asked to step on the pedobarograph three times with each foot during normal walking. The sensor platform was hidden with a thin plastic cover to prevent the patient from changing the length of the stride in order to strike it. We obtained values for total area of maximum pressure (in square centimeters), peak pressure of

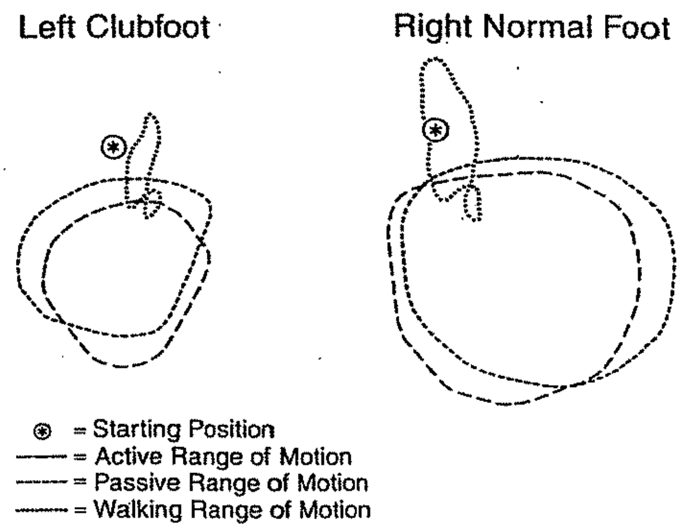


FIG. 2

Tracing of the electrogoniometric record from a forty-two-year-old man who had clubfoot on the left and an excellent result. There is a marked decrease in the active and passive ranges of motion of the clubfoot as well as the range during walking. This was a uniform finding.

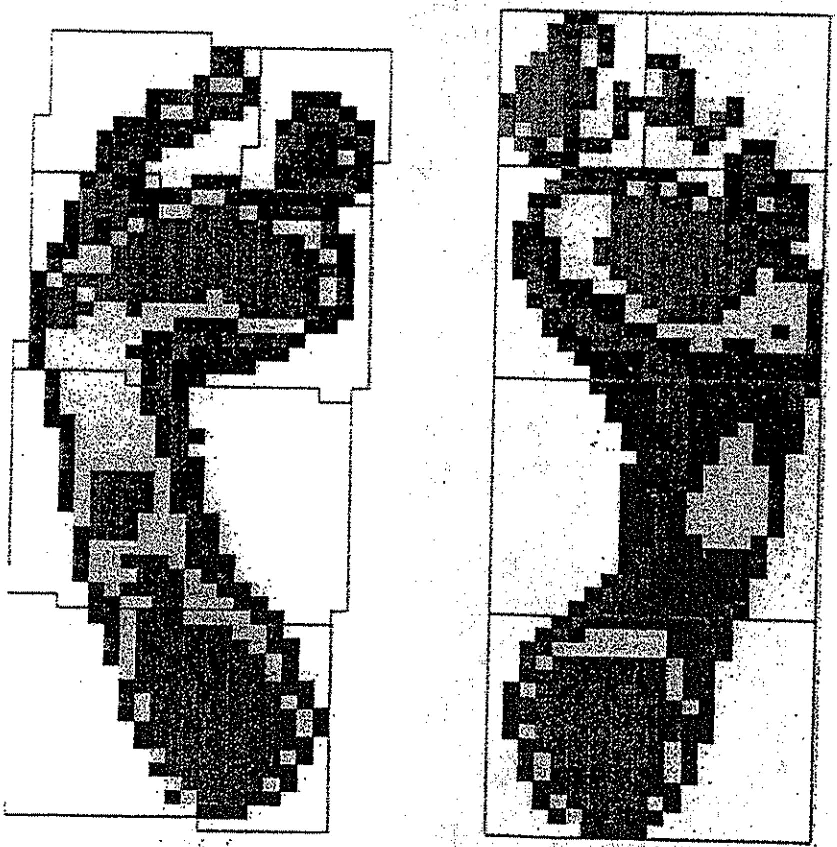


FIG. 3

Photograph of the pictures generated by the pedobarograph of the patient in Fig. 2. Each small square is generated by an individual press sensor. The lines dividing the foot into heel, midfoot, forefoot, lateral toes, and great toe were custom-fitted for each foot. The clubfoot (l shows less pressure on the heel (light gray indicates a higher pressure than dark gray) and more pressure in the area of the midfoot (v light gray indicates the highest contact pressure) than the normal, contralateral foot, suggesting a limitation of dorsiflexion with m weight-bearing on the midfoot and less on the heel. The clubfoot has a larger area of high pressure in the forefoot and more lateral press than the normal foot.

the maximum-pressure picture (in newtons per square centimeter), total force (normalized to body weight) of the maximum-pressure picture (expressed as the percentage of body weight), pressure time integral (newton-seconds per square centimeter), and force time integral normalized to body weight (expressed as the percentage of body weight multiplied by seconds). These parameters were chosen to assess the different kinds of energy absorbed by the foot. The peak pressure area, peak pressure, and pressure time integral are measurements of different absolute energies experienced by the foot. The force measurements compensated for different body weights. The integrals of pressure and force reflect the total energy experienced, while the peak pressures reflect the extreme energy experienced. We investigated all of these parameters because we did not know *a priori* which might be associated with pain and function. The foot was divided into five areas (heel, midfoot, metatarsal heads, great toe, and lateral toes), and separate values were obtained for each area as well as for the entire foot (Fig. 3). In the evaluation of the nineteen patients who had unilateral clubfoot, we used the normal foot as a comparison (not a true cc trol) for measurements.

Comparison Group

We randomly selected ninety-seven individuals w were in the waiting area of the ophthalmology outp tient clinic of our institution to fill out a questionnai regarding pain and function of the foot that was iden cal to that completed by the patients. The individu were within the age-range of our patients (twenty-o to fifty years old) and were screened only for the a sence of congenital deformity of the foot. On the ba of the initial thirty-four responses, we established c teria for excellent, good, and poor function of the fo For a foot to be considered excellent, there had to l no functional limitation and only occasional mild pai However, since many of the individuals in the con parison group had some pain and functional problen associated with the feet, and since we do not expe treatment of clubfeet to result in feet that are superi to those without congenital deformity, we thought th feet with minor problems should be classified as goo

Specifically, our classification was as follows. An excellent foot does not limit activities of daily living and either is never painful or occasionally causes mild pain; a good foot occasionally limits activities of daily living or strenuous activities or is painful after strenuous activities; and a poor foot limits daily activities or routine walking or is painful during daily activities or walking, or at night. If the answer to one of the two questions regarding pain or function was in the poor category, the foot was regarded as poor.

We compared the individuals who did not have congenital deformity of the foot with the patients, with respect to each item on the questionnaire. All of the individuals were included except in the evaluation of low-foot-demand occupations compared with high-foot-demand occupations. Nine nurses in the comparison group were excluded from that analysis because we could not distinguish among nurses' aides, administrative nurses, ward nurses, and operating-room nurses. The demands on the feet vary widely among these occupations, and thus classification into low-foot-demand or high-foot-demand categories was not possible. None of the patients who had clubfoot was a nurse. Eight other individuals who did not have congenital deformity of the foot did not note their occupation on the questionnaire. Thus, eighty of the ninety-seven questionnaires from the comparison group were used for analysis of occupation.

Results

The average age of the forty-five patients at the time of follow-up was thirty-four years (range, twenty-five to forty-two years).

Of the seventy-one feet, five were treated with only manipulation, plaster casts, and a Denis Browne splint. Twenty-seven feet also had an Achilles tenotomy. Thirty-eight feet also had a transfer of the anterior tibial tendon. Six of these thirty-eight feet were treated, in addition, with at least one of these procedures: plantar fasciotomy (four feet), recession of the extensor hallucis longus tendon to the neck of the first metatarsal (four feet), transfer of the extensor digitorum communis tendon to the metatarsals (two feet), and transfer of the peroneus longus tendon to the peroneus brevis (one foot). One patient had transfer of the posterior tibial tendon to the dorsum of the foot through the interosseous membrane. One patient who had a bilateral transfer of the anterior tibial tendon also had a bilateral triple arthrodesis. This patient is included in the overall outcome analysis (as a poor result) but is not included in the comparison of excellent or good results and poor results with respect to the questionnaire, radiographs, physical examination, pedobarographic data, or electrogoniometric data because we were attempting to find factors associated with excellent or good outcomes compared with poor outcomes in relation to clubfeet, not in relation to triple arthrodeses.

Using the outcome criteria of pain and limitation of function of the foot, we found that twenty-eight (62 per cent) of the patients had an excellent result (Figs. 4-A and 4-B), seven (16 per cent) had a good result, and ten (22 per cent) had a poor result, compared with sixty-one (63 per cent), twenty-one (22 per cent), and fifteen (15 per cent), respectively, in the comparison group. Because of evident demographic differences between the patients and the individuals in the comparison group, we controlled for differences in sex and occupational frequencies with use of the Cochran-Mantel-

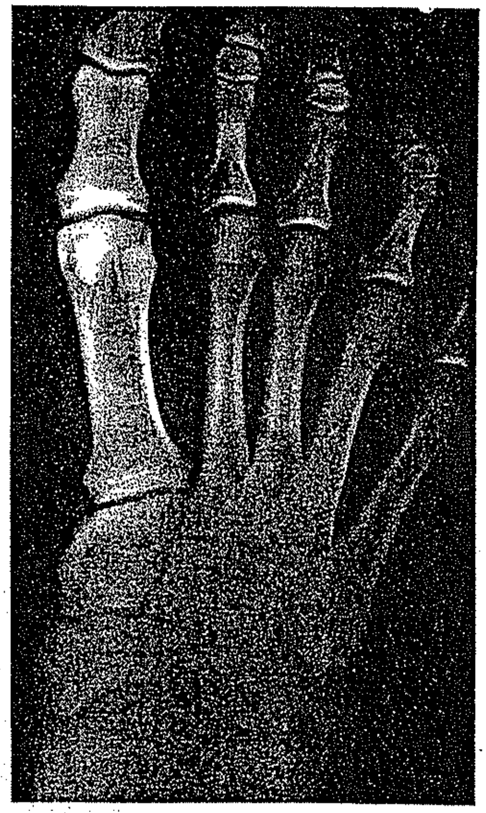


FIG. 4-A

Figs. 4-A and 4-B: Radiographs of a thirty-two-year-old man who had a clubfoot on the right. This patient had one of the best radiographic results in the series. He did not have the decreased talocalcaneal angle and the residual medial displacement of the navicular commonly seen in the other patients.

Fig. 4-A: Anteroposterior radiograph of the right foot.

FIG. 4-B

Lateral radiograph of the right foot.

Haenszel test of general association[8,9]. No significant difference was found between the patients and the comparison group with or without this adjustment.

Results of the Questionnaire

Twenty-five (56 per cent) of the patients were junior-high or high-school graduates, and twenty (44 per cent) had attended college without graduating or were college graduates. Thirty (31 per cent) of the individuals in the comparison group were junior-high or high-school graduates, and sixty-seven (69 per cent) had attended college without graduating or were college graduates. Analysis of occupations revealed that twenty-four (55 per cent) of the patients had a low-foot-demand occupation and twenty (45 per cent) had a high-foot-demand occupation, compared with sixty-one (76 per cent) and nineteen (24 per cent), respectively, for the eighty individuals for whom occupational data were available in the comparison group. Twenty-two (54 per cent) of the forty-one patients who answered the question participated in sports activities at least once a week, compared with thirty-nine (40 per cent) of the ninety-seven individuals in the comparison group. Twenty-four (55 per cent) of the forty-four patients who responded were able to participate in unlimited activities, compared
seventy-one (73 per cent) of the individuals. Of the f
three patients who answered the question, eleven (2
cent) thought that they could walk any distance wit
discomfort in the foot, compared with forty-four (4
cent) of the individuals. Sixteen patients (36 per c
had received treatment for clubfoot after care at
University of Iowa had been completed. This treatr
consisted of anti-inflammatory medications or sho
serts, or both, for all but two patients. One patient
used an ankle-foot orthosis in the past and the other,
had had a bilateral triple arthrodesis, had several a
tional operations on both feet. Thirty-three (73 per c
of the patients were very satisfied or satisfied with
end result of the treatment. We were able to lo
questionnaires completed by seventeen of the twe
nine patients who had participated in the previous stu
Comparison of the responses revealed no change du
the intervening thirteen to sixteen years.

Results of the Physical Examination

There was no difference in the length of the lo
extremity with the clubfoot compared with the norn
contralateral extremity of the patients who had uni

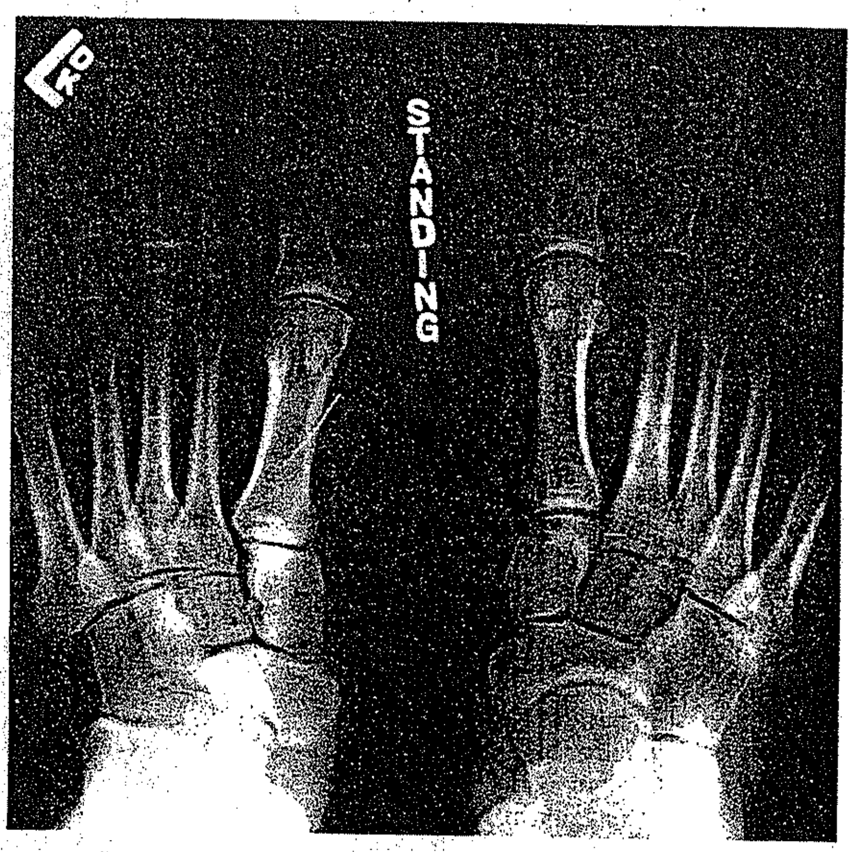


FIG. 5-A

Figs. 5-A, 5-B, and 5-C: Radiographs of a thirty-seven-year-old man who had a clubfoot on the left and an excellent functional result. The is navicular wedging and residual medial displacement of the navicular of the clubfoot. The small dorsal osteophyte of the talar head is typic of the so-called degenerative changes seen. The small osteophyte of the neck of the talus seen in the normal, right foot is identical to the mo common so-called degenerative change seen in clubfeet. The apparent talar flattening was graded as moderate because, while the contour the talar body was not normal, the talar body was not completely flat.

Fig. 5-A: Anteroposterior radiograph of both feet.

eral clubfoot. The circumference of the calf was an average of three centimeters smaller on the involved side. The clubfoot of two patients was the same length as the normal foot, and that of sixteen patients was an average of one centimeter shorter than the normal foot. The clubfoot of three patients was the same width as the normal foot, and that of fifteen patients was an average of 0.5 centimeter narrower.

A callus formed, usually under the fourth or fifth metatarsal head, in ten patients. Twelve patients had tenderness to palpation, which was around the ankle joint in five, along the plantar fascia in three, under the metatarsal heads in three, and at the insertion of the Achilles tendon in one. The gait of forty-one patients was considered normal. Four patients, including the one who had had a bilateral triple arthrodesis, had a slight limp. All of the patients were able to walk on the toes; however, three were unable to walk on the heels because of limited dorsiflexion.

Three feet (4 per cent) had evidence of mild cavus deformity on visual inspection. All of the transferred anterior tibial tendons were functioning and grade 5. Six feet that had had a transfer of the anterior tibial tendon had trace weakness compared with the normal foot. Motor function of the posterior tibialis was normal in sixty-six clubfeet and had trace weakness in five. The strength of the gastrocnemius-soleus was normal in all but two feet, which had trace weakness. The peroneals had normal strength in sixty-seven clubfeet and had trace weakness in four. Function of the extensor hallucis longus was grade 0 in two patients who had been treated with recession of the extensor hallucis longus and was weak (range, grade 3 to trace weakness) in nine feet.

FIG. 5-B

Lateral radiograph of the left foot.

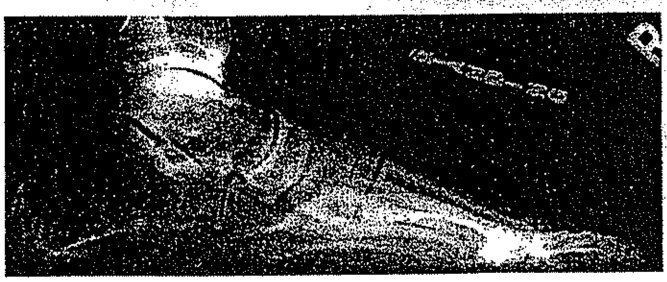


FIG. 5-C

Lateral radiograph of the right foot.

TABLE I

RADIOGRAPHIC RESULTS

Angle	Clubfeet (N = 69)*	Normal Feet (N = 19)*	P Value
Anteroposterior *(degrees)*			
Talocalcaneal	17 ± 8	23 ± 8	0.005
Calcaneus-fifth metatarsal	−8 ± 10	−3 ± 9	0.09
Talus-first metatarsal	1 ± 11	1 ± 8	0.86
Lateral *(degrees)*			
Talocalcaneal[18]	30 ± 7	44 ± 9	<0.0001
Talus-first metatarsal	5 ± 6	−1 ± 9	0.007
Calcaneus-first metatarsal	145 ± 9	138 ± 10	0.006
First-fifth metatarsal	16 ± 5	16 ± 5	0.74

*The values are given as the mean and the standard deviation.

Function of the flexor hallucis longus was normal in all feet except for one that had trace weakness. Sixty-six clubfeet had normal function of the extensor digitorum communis; four had trace weakness; and one, which had been treated with transfer of the extensor digitorum communis tendon, had no function of that tendon. The function of the flexor digitorum longus was normal in all feet. Nineteen patients were unable to do forty rapid toe-ups on the affected side. In contrast, only one patient was unable to do forty toe-ups on the normal side.

The passive range of motion of the foot was assessed with a hand-held goniometer. Dorsiflexion averaged 6 degrees (range, −2 to 18 degrees) for the clubfeet and 17 degrees (range, 4 to 22 degrees) for the normal feet. Plantar flexion averaged 31 degrees (range, 15 to 45 degrees) for the clubfeet and 41 degrees (range, 30 to 60 degrees) for the normal feet. The average varus deformity of the hind part of the clubfeet was 14 degrees (range, 0 to 30 degrees), compared with 24 degrees (range, 2 to 36 degrees) for the normal feet. The average valgus deformity of the hind part of the clubfeet was 1.6 degrees (range, −2 to 10 degrees), compared with 5.8 degrees (range, 0 to 20 degrees) for the normal feet. The position of the heel, recorded with the patient standing, averaged 0.3 degree of valgus (range, 5 degrees of varus to 8 degrees of valgus) for the clubfeet and 1.5 degrees of valgus (range, neutral to 5 degrees of valgus) for the normal feet.

Radiographic Results

The radiographs revealed a number of differences between the clubfeet and the normal, contralateral feet (Table I). Both the anteroposterior and the lateral talocalcaneal angles were decreased in the clubfeet, compared with those in the normal feet, by an average of 6 degrees for the anterior angle and an average of 14 degrees for the lateral angle. These angles generally reflect residual varus deformity of the subtalar joint. The lateral talus-first metatarsal angle and the lateral calcaneus-first metatarsal angle were slightly greater in the clubfeet than in the normal feet (5 ± 6 degrees and 145 ± 9 degrees compared with −1 ± 9 degrees and 138 ± 10 degrees, respectively), reflecting a mild residual cavus deformity

TABLE II
ELECTROGONIOMETRIC RESULTS

Range of Motion	Clubfeet (N = 62)*	Normal Feet (N = 16)*	P Value
Passive *(degrees)*			
Dorsiflexion	0 ± 7	11 ± 12	0.003
Plantar flexion	42 ± 12	52 ± 9	0.003
Eversion	13 ± 8	15 ± 9	0.28
Inversion	21 ± 11	34 ± 11	0.0001
Active *(degrees)*			
Dorsiflexion	−4 ± 8	6 ± 10	<0.0001
Plantar flexion	39 ± 11	51 ± 9	0.0001
Eversion	10 ± 7	14 ± 8	0.06
Inversion	17 ± 11	34 ± 10	<0.0001
Walking *(degrees)*			
Dorsiflexion	9 ± 15	13 ± 5	0.006
Plantar flexion	14 ± 6	13 ± 5	0.57
Eversion	6 ± 4	3 ± 5	0.03
Inversion	6 ± 5	10 ± 6	0.02
Area within passive range-of-motion circle *(cm²)*	29 ± 14	61 ± 29	0.0005

*The values are given as the mean and the standard deviation.

of the midfoot. The lateral first-fifth metatarsal angle was identical in the club and normal feet (16 ± 5 degrees), reflecting a complete reduction of the cavus deformity that had been present at birth. Measurements of adductus of the midfoot gave conflicting results. The anteroposterior talus-first metatarsal angle was similar in the club and normal feet (1 ± 11 degrees compared 1 ± 8 degrees); however, the anteroposterior calca fifth metatarsal angle showed a greater average ab tion in the clubfeet (−8 ± 10 degrees) than in the no feet (−3 ± 9 degrees.)

Forty-two clubfeet (61 per cent) had navicular w ing. It was mild in nineteen, moderate in sixteen, severe in seven. Forty-seven clubfeet (68 per cent) talar flattening. It was mild in fifteen, moderate in n teen, and severe in thirteen. Degenerative changes noted in twenty-four (35 per cent) of the clubfeet. T changes were usually mild and consisted of os phytes on the dorsal aspect of the talus, the ante aspect of the distal end of the tibia, or the talonavic joint. Two patients were noted to have ossificatio the Achilles tendon, and both had been managed open operative lengthening. Twenty-nine patients had radiographs made for the previous study[7]. Only of these patients had evidence of increased degen tive changes, consisting of slightly larger osteophyte the dorsal aspect of the talar neck (Figs. 5-A thro 6-C), when the most recent radiographs were compa with the previous ones.

Electrogoniometric Results

Electrogoniometric analysis revealed markedly creased passive and active dorsiflexion, plantar flexi

FIG. 6-A

Figs. 6-A, 6-B, and 6-C: Radiographs of a thirty-nine-year-old woman who had bilateral clubfoot and a poor functional result. The feet we among the most radiographically deformed in the series. There is severe navicular wedging of the right foot and residual medial displaceme of the navicular. Both feet have a shortened, crushed-appearing navicular and osteophytes of the dorsal aspect of the talar neck.
Fig. 6-A: Anteroposterior radiographs of both feet.

and inversion of the clubfeet compared with those of the normal feet (Table II). Passive and active eversion were not markedly different. During walking, the clubfeet had less dorsiflexion and inversion and more eversion than the normal feet did. There was no marked difference in plantar flexion during walking. The magnitude of the difference in motion between the clubfeet and the normal feet was much less during walking than during the active and passive ranges of motion. During walking, the clubfeet had only 4 degrees less dorsiflexion (9 ± 15 compared with 13 ± 5 degrees [average and standard deviation]) and inversion (6 ± 5 compared with 10 ± 6 degrees), 3 degrees more eversion (6 ± 4 compared with 3 ± 5 degrees), and 1 degree more plantar flexion (14 ± 6 compared with 13 ± 5 degrees) than the normal feet did. It is noteworthy that the amount of dorsiflexion during walking (9 ± 15 degrees) was much greater than that during the passive range of motion (0 ± 7 degrees) or the active range of motion (−4 ± 8 degrees). This was probably because of the greater force exerted by the weight of the body across the ankle, subtalar, and midfoot joints and the ligaments during walking compared with that generated by active and passive range-of-motion testing. The area within the passive range-of-motion circle was strikingly smaller for the clubfeet (29 ± 14 square centimeters) than for the normal feet (61 ± 29 square centimeters).

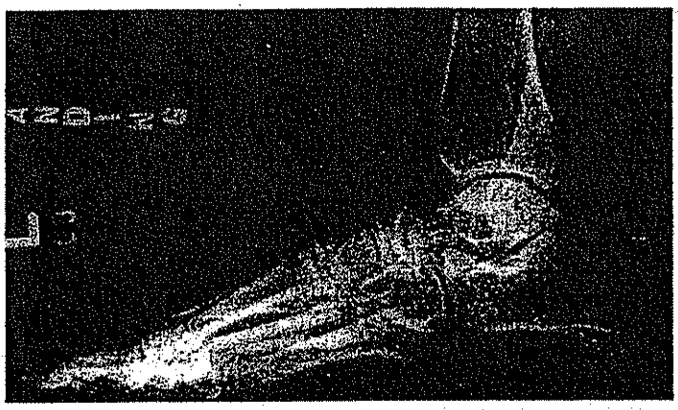


FIG. 6-B
Lateral radiograph of the left foot.

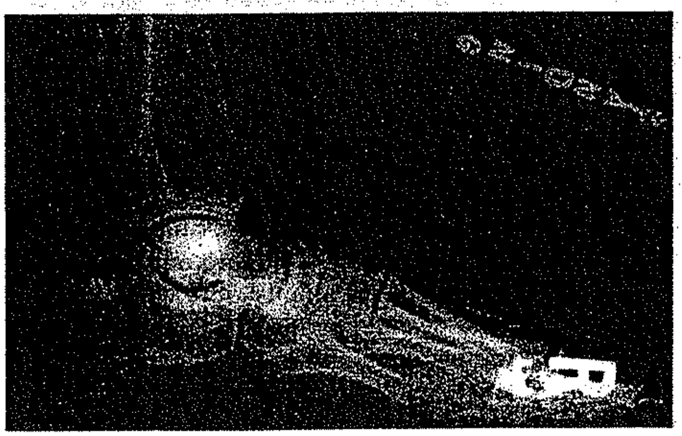


FIG. 6-C
Lateral radiograph of the right foot.

TABLE III
PEDOBAROGRAPHIC RESULTS
(PARAMETERS WITH SIGNIFICANT DIFFERENCES)

Section of the Foot	Clubfeet (N = 54)*	Normal Feet (N = 14)*	P Value
Heel			
Total force of maximum-pressure picture *(per cent body weight)*	66 ± 12	74 ± 14	0.04
Peak pressure *(N/cm²)*	30 ± 8	37 ± 12	0.06
Midfoot			
Total force of maximum-pressure picture *(per cent body weight)*	35 ± 14	23 ± 11	0.003
Peak pressure *(N/cm²)*	18 ± 8	12 ± 4	0.001
Pressure time integral *(N-secs./cm²)*	6 ± 2	4 ± 2	0.009
Force time integral *(per cent body weight × secs.)*	11 ± 5	7 ± 5	0.01
Metatarsal heads			
Total area of maximum pressure *(cm²)*	51 ± 7	56 ± 8	0.04
Lateral toes			
Total area of maximum pressure *(cm²)*	9 ± 2	7 ± 2	0.01
Force time integral *(per cent body weight × secs.)*	2 ± 1	1 ± 1	0.04

*The values are given as the mean and the standard deviation.

Pedobarographic Results

Analysis of the pedobarographic data revealed no differences between the clubfeet and the normal, contralateral feet, with regard to any parameter, when the entire foot was assessed (Table III). However, there were differences in specific regions of the foot. The heels of the clubfeet had a lesser peak pressure (30 ± 8 compared with 37 ± 12 newtons per square centimeter) and a lesser total force in the area of maximum pressure (66 ± 12 compared with 74 ± 14 per cent of body weight). The greatest difference between the clubfeet and the normal feet was in the region of the midfoot. Total force in the area of maximum pressure, peak pressure, pressure time integral (the total pressure during one stance phase), and force time integral (the total force during one stance phase) were all greater in the clubfeet than in the normal feet. The total force in the area of maximum pressure was 35 ± 14 per cent of body weight for the clubfeet, compared with 23 ± 11 per cent of body weight for the normal feet; the peak pressure was 18 ± 8 compared with 12 ± 4 newtons per square centimeter; the pressure time integral was 6 ± 2 compared with 4 ± 2 newton-seconds per square centimeter; and the force time integral was 11 ± 5 compared with 7 ± 5 per cent of body weight multiplied by seconds. The clubfeet also had a smaller area of maximum pressure under the metatarsal heads (51 ± 7 compared with 56 ± 8 square centimeters). The lateral toes of the clubfeet had a larger total area of maximum pressure and a greater

TABLE IV

COMPARISON OF EXCELLENT OR GOOD OUTCOMES WITH POOR OUTCOMES IN CLUBFEET (PARAMETERS WITH SIGNIFICANT DIFFERENCES OR APPARENT ASSOCIATION WITHOUT SIGNIFICANCE)

Parameter	Outcome: Excellent or Good*	Outcome: Poor*	P Value
Occupation			
High-foot-demand	12	8	0.03
Low-foot-demand	22	2	
Passive dorsiflexion† *(degrees)*	7 ± 4 (n = 57)	4 ± 4 (n = 12)	0.03
Rapid toe-ups (max., 40)	38 ± 4 (n = 57)	28 ± 10 (n = 12)	0.005
Body-mass index‡	26 ± 5 (n = 57)	30 ± 6 (n = 12)	0.07
Anteroposterior calcaneus-fifth metatarsal angle *(degrees)*	−6 ± 10 (n = 57)	−13 ± 7 (n = 12)	0.03
Pressure time integral of entire foot *(N-secs./cm²)*	27 ± 6 (n = 43)	21 ± 7 (n = 7)	0.04
Peak pressure under heel *(N/cm²)*	31 ± 8 (n = 43)	25 ± 5 (n = 7)	0.07
Force time integral of metatarsal heads *(per cent body weight × secs.)*	30 ± 7 (n = 43)	27 ± 2 (n = 7)	0.07

*Except for occupation, the values for each parameter are given as the mean and the standard deviation.

†As measured with the hand-held goniometer.

‡The weight in kilograms divided by the square of the height in meters.

force time integral than those of the normal feet (9 ± 2 compared with 7 ± 2 square centimeters and 2 ± 1 compared with 1 ± 1 per cent of body weight multiplied by seconds, respectively).

Parameters Associated with an Excellent or Good Result Compared with a Poor Result

Although there were marked differences between the clubfeet and normal feet with regard to almost all of the measurements, very few helped to discriminate between an excellent or good functional outcome and a poor functional outcome (Table IV). Factors that were significant included occupation (p = 0.03), anteroposterior calcaneus-fifth metatarsal angle (p = 0.03), passive dorsiflexion measured with the hand-held goniometer (p = 0.03), pressure time integral of the entire foot (p = 0.04), and number of rapid toe-ups that the patient was able to perform[7] (p = 0.005).

Twenty-two (92 per cent) of the twenty-four feet of the patients who had a low-foot-demand occupation had an excellent or good result and two (8 per cent) had a poor result, compared with twelve (60 per cent) and eight (40 per cent), respectively, of the twenty feet of the patients who had a high-foot-demand occupation (p = 0.03, Fisher exact test[15]).

The average anteroposterior calcaneus-fifth metatarsal angle was −6 ± 10 degrees in the feet that had an excellent or good outcome compared with −13 ± 7 degrees in the feet that had a poor outcome. Passive dorsiflexion, measured clinically, averaged 7 ± 4 de[grees] for the feet that had an excellent or good outcom[e] [and] 4 ± 4 degrees for those that had a poor outcome [(p =] 0.03). According to the pedobarographic measurem[ents,] the feet that had an excellent or good outcom[e had] an average pressure time integral of the entire fo[ot of] 27 ± 6 newton-seconds per square centimeter [com]pared with 21 ± 7 newton-seconds per square c[enti]meter for those that had a poor outcome (p = 0.04). [The] rapid toe-up test revealed an average of 38 ± 4 to[e-ups] for the feet that had an excellent or good outcome [com]pared with 28 ± 10 for the feet that had a poor outc[ome] (p = 0.005).

Three other measurements approached the lev[el of] significance (p = 0.05). The average body-mass i[ndex] was 26 ± 5 kilograms per square meter for the pati[ents] who an excellent or good result and 30 ± 6 kilogr[ams] per square meter for those who had a poor result [(p =] 0.07). The average peak pressure under the heel [was] greater (31 ± 8 newtons per square centimeter) for [the] feet that had an excellent or good outcome than [for] those that had a poor outcome (25 ± 5 newtons [per] square centimeter). The force time integral was 30 [±7] per cent body weight multiplied by seconds for the [pa]tients who had an excellent or good outcome and 2[7 ±] 2 per cent body weight multiplied by seconds for th[ose] who had a poor outcome (p = 0.07).

With the limited number of patients studied, [we] could detect no association between the over-all c[out]come and the remaining ranges of motion measu[red] clinically or with the electrogoniometer, the remain[ing] pedobarographic measurements, or the remaining [an]gles measured radiographically. We found no differe[nce] between the different modes of treatment (manipu[la]tion with or without percutaneous Achilles tenoto[my] compared with transfer of the anterior tibial tend[on] compared with additional procedures) and the over-[all] rating.

Discussion

We defined our outcome groups according to tw[o] questions: one regarding the function of the foot duri[ng] activities of daily living and strenuous activities and th[e] other regarding pain in the foot. This subjective asses[s]ment of outcome is doubtless affected by factors oth[er] than those reflecting the objective quality of the corre[c]tion of the initial deformity, such as mobility, suppleness, strength, and absence of residual deformity of the foo[t]. We interviewed a few patients in stressful life circum[stances] who had multiple physical symptoms in additi[on] to pain in the foot. These patients were considered t[o] have a poor result despite a good result with regard t[o] the standard radiographic and clinical criteria. In con[trast], some feet that were stiff and had mild residua[l] deformity had an excellent functional outcome. Individ[u]al responses to an absolute level of abnormality of th[e] foot doubtless depend greatly on the over-all satisfac[tion]

tion of the patient with his or her life. Despite this limitation, we believe that the subjective results were a better measure of the long-term outcome than objective radiographic or physical parameters that have not been demonstrated to correlate with pain and function of the foot. We think that rating scales based on such parameters are arbitrary and uninformative. Certainly, better techniques for the assessment of subjective results will improve the quality of future outcome studies. Because pain in the feet is common in adults, we believe that evaluation of a group of individuals who did not have congenital deformity of the foot was important to help us to choose our outcome criteria. We would not expect people who have a clubfoot to have better function than those who do not have such a congenital deformity. Some pain in the feet after strenuous activities is common, as evidenced by the fifteen individuals (15 per cent) who had a poor rating in the comparison group. Thirty-five (78 per cent) of the forty-five patients had an excellent or good result compared with eighty-two (85 per cent) of the ninety-seven individuals in the comparison group.

Comparison of the results of the present study with those of other studies is difficult because of the many evaluation schemes employed and the variable durations of follow-up. The results of our study caused us to question the value of short-term results based on radiographic or range-of-motion criteria because these factors did not distinguish between the excellent or good outcomes and the poor outcomes in our patients. Furthermore, pain is not an appropriate outcome criterion for children, as even feet with moderately severe deformity do not usually become painful until adolescence or adulthood.

In 1979, Turco reported the results in a series of 240 clubfeet that had been treated with one-stage posteromedial release with internal fixation. He reported an excellent or good result for 125 (84 per cent) of 149 feet that had been followed for two to fifteen years. His assessment of the results was based on radiographic criteria, range of motion, and clinical appearance but not on function or symptoms. Otremski et al., in 1987, reported the results of the Turco operation in forty-seven feet. As assessed with a grading system similar to that used by Turco, forty-one (87 per cent) of forty-seven feet that were followed for eight to fourteen years had an excellent or good result. Thirty-six (77 per cent) of forty-seven feet that were followed for four to eight years in a study by Ricciardi-Pollini et al. had an excellent or good result. Ricciardi-Pollini et al. also evaluated the results according to clinical and radiographic criteria without considering function or symptoms. Bensahel et al., in 1987, reported a good result, after six to ten years of follow-up, for eighty-nine (88 per cent) of 101 feet that had been treated with one-stage medioposterior release[3]. They assessed the results on the basis of the clinical and radiographic alignment, mobility of the joint, gait, wear pattern of the shoes, and findings of plantar photopodometry. No mention of symptoms or function was made. In 1985, Simons compared two groups of patients who had been managed with either complete subtalar release or a less extensive procedure (posterior, posteromedial, or posteromedial and lateral release). He reported a satisfactory result, after a two to four-year follow-up, for eighteen (72 per cent) of twenty-five feet that had been treated with complete subtalar release compared with thirteen (50 per cent) of twenty-six that had been treated with less extensive means. For this short-term follow-up study, Simons used a clinical and radiographic evaluation scale, and the result for any patient who had pain with normal activity was considered unsatisfactory. Hutchins et al., in 1985, reported the results for 252 feet that had been treated with early posterior release and that had been followed for an average of fifteen years and ten months. With use of the grading system of Laaveg and Ponseti, the result in 81 per cent of the feet was considered satisfactory, but only 57 per cent were thought to have an excellent or good result.

The validity of the criteria used to determine an excellent or good outcome in these studies is questionable because few of the measured variables correlated with an excellent or good outcome in the present long-term follow-up study. It is likely, however, that the requisites for an excellent or good outcome may be different for different treatment regimens.

Others have managed patients with a combination of serial casts and limited operative procedures to correct resistant deformities after treatment with a cast alone[2,6,7,12,19]. Wynne-Davies, in 1964, reported the results for 121 feet that had been treated with serial casts until full correction was obtained and then were treated with a Denis Browne splint. Two-thirds of the patients needed an operation after use of the casts and splint, and one-third were managed with closed methods. Wynne-Davies found a correlation between radiographic appearance and clinical outcome at the age of fifteen years. A clinical and radiographic scoring system was set up but no results were given. Fifteen (18 per cent) of eighty-four patients had occasional pain and fatigued easily. The average duration of follow-up was not stated.

Ninety-two (88 per cent) of the 104 feet in the 1980 study by Laaveg and Ponseti had a satisfactory functional result at an average of nineteen years. The authors found that transfer of the anterior tibial tendon was important for the prevention of relapse. This was also reported by Wynne-Davies and Ricciardi-Pollini et al. but not by Bensahel et al.[2], who stated that tendon transfers are not indicated in the treatment of clubfoot. In 1990, Aronson and Puskarich compared the results of different types of treatment and found that feet that had been treated with casts or with casts and heel-cord lengthening tended to have the least disability and deformity except with regard to correction of the talocalcaneal index. They found that posteromedial release improved the talocalcaneal index but reduced both the range of motion of the ankle and the plantar flexion strength compared with those in the feet that had been treated with casts. None of these studies had a control group with which the results could be compared.

We found that the clubfeet in our study were markedly different than the normal, contralateral feet with respect to almost every evaluation parameter. The clubfeet had a decreased range of motion as measured with both a hand-held goniometer and an electrogoniometer. It is noteworthy that passive and active dorsiflexion was much more limited than dorsiflexion during walking. Standard testing of the passive range of motion may not reflect accurately the range of motion available during normal function of the foot. The absence of correlation between the range of motion and the outcome in the present study does not necessarily mean that motion is unimportant for function of the foot. Rather, the range of motion was not related to the outcome within the ranges obtained with this specific treatment regimen.

It is possible that the outcome did not correlate with various radiographic measurements because this treatment technique resulted in sufficient correction for satisfactory function of the foot. Certainly, correction of the talocalcaneal angles to normal values does not seem critical with this treatment regimen, which resulted in visually plantigrade feet despite persistent radiographic abnormality. With extensive releases, the radiographic angles may predict outcome, particularly in overcorrected feet. We have difficulty explaining the correlation of an increased calcaneus-fifth metatarsal angle with a poor result. In our experience, residual adduction or abduction of the forefoot has not seemed to be associated with poor functional results in clubfoot or other deformities of the foot. It is possible that this association occurred by chance since we performed a large number of statistical comparisons (approximately 250). For example, with 250 independent tests each performed at the 0.05 level of significance, there is a nearly 100 per cent chance that at least one test will be falsely positive. Alternatively, feet that were stiffer at birth may have necessitated a greater abduction of the forefoot in order to rotate the calcaneus out of varus, and this may have resulted in residual abduction. This finding might then correlate with the initial severity rather than directly with the functional outcome. Our hypothesis is supported by a modest correlation between smaller anteroposterior talocalcaneal angles and more negative (abducted) calcaneus-fifth metatarsal angles, as demonstrated on a scatterplot display. This interpretation was supported by a positive association with both the parametric (Pearson) and non-parametric (Spearman) correlation coefficients of 0.33 and 0.30, respectively. The null hypothesis (no correlation between these two angles) was rejected on the basis of these correlation coefficients ($p = 0.007$, Pearson, and $p = 0.01$, S man). More severely deformed feet might have ne tated a greater abduction of the forefoot throug midfoot to obtain clinical correction if the calcaneu less correctable beneath the talus.

Although mild residual deformity was com only minimum signs of early degenerative osteoar sis were found. The absence of any progression of r graphic signs of degenerative osteoarthrosis in the or ankle suggests that the present results will persis many years.

Pedobarographic evaluation showed no differe between the clubfeet and the normal, contralateral when the entire foot was considered, but there differences in specific regions of the foot. The hee the clubfeet had a lesser peak pressure and total f of the maximum-pressure picture than those of the mal feet. This, coupled with the increased pressure the mid-part of the clubfeet, suggests that the limita of dorsiflexion results in a transfer of weight from heel to the midfoot in normal walking. The theory this is not due to a rocker-bottom deformity of the r foot is supported by the slightly greater cavus deforr of the midfoot seen on radiographic analysis. The creased area of maximum pressure under the metata heads and the mildly increased total area of maxim pressure and force time integral under the lateral t of the clubfeet suggest a mild lateral transfer of weig bearing compared with that in the normal feet. The l of association of any of these differences with an exc lent or good result compared with a poor result sugge that they are within the tolerance of feet — that is, tl do not interfere with good function.

Physicians are limited in their ability to control variables that we found to be associated with a bet outcome. Early counseling of the patient to obtair sedentary job may be appropriate. Whether limiti heavy use of the foot in an occupation or occupatio satisfaction is more important in the determination o patient's perceptions of pain and functional limitati was not addressed in this study. On the basis of c conversations with patients, we surmise that both fa tors are important. Patients should also be advised avoid excessive weight gain.

The records from our hospital indicate that ninet two (88 per cent) of 104 clubfeet seen from 1950 to 19 were successfully treated with manipulation and cas followed by use of a Denis Browne splint, with transf of the anterior tibial tendon to the third cuneiform dynamic supination developed (as was described l Laaveg and Ponseti). There is a wide spectrum of d formity in congenital clubfoot, with some feet beir very supple and easily correctable with four or five cas and others being resistant to manipulation and prone recurrence. There is as yet no system to determine, infancy, which feet will be easily correctable and whic will need operative treatment[4]. Our data suggest th the cavus and adductus deformities are always easily corrected with casts and that the varus deformity of the hindfoot and the equinus determine whether more extensive operative treatment is necessary to obtain a plantigrade foot.

In the present study, most of the patients had a satisfactory long-term result. There was no deterioration in the results of the feet that had been reported on in 1980[7]. With the use of pain and limitation of function, as reported by the patients, as our outcome measures, this group of patients who had clubfeet were doing nearly as well as the comparison group of individuals who did not have congenital deformity of the foot. Continued follow-up is necessary to determine if these results will persist throughout life.

NOTE: The authors thank Ignacio Ponseti for helpful suggestions during the preparation of this manuscript and for allowing them to review the cases of his patients. They also thank Charles S. Davis for the time and effort expended in the statistical analysis of the data.

References

1. **Aronson, J., and Puskarich, C. L.:** Deformity and disability from treated clubfoot. *J. Pediat. Orthop.*, 10: 109-119, 1990.
2. **Bensahel, H.; Catterall, A.; and Dimeglio, A.:** Practical applications in idiopathic clubfoot: a retrospective multicentric study in EPOS. *J. Pediat. Orthop.*, 10: 186-188, 1990.
3. **Bensahel, H.; Csukonyi, Z.; Desgrippes, Y.; and Chaumien, J. P.:** Surgery in residual clubfoot: one-stage medioposterior release "à la carte." *J. Pediat. Orthop.*, 7: 145-148, 1987.
4. **Catterall, A.:** A method of assessment of the clubfoot deformity. *Clin. Orthop.*, 264: 48-53, 1991.
5. **Hutchins, P. M.; Foster, B. K.; Paterson, D. C.; and Cole, E. A.:** Long-term results of early surgical release in club feet. *J. Bone and Joint Surg.*, 67-B(5): 791-799, 1985.
6. **Karski, T., and Wosko, I.:** Experience in the conservative treatment of congenital clubfoot in newborns and infants. *J. Pediat. Orthop.*, 9: 134-136, 1989.
7. **Laaveg, S. J., and Ponseti, I. V.:** Long-term results of treatment of congenital club foot. *J. Bone and Joint Surg.*, 62-A: 23-31, Jan. 1980.
8. **Landis, J. R.; Heyman, E. R.; and Koch, G. G.:** Average partial association in three-way contingency tables: a review and discussion of alternative tests. *Internat. Statist. Rev.*, 46: 237-254, 1978.
9. **Mantel, N., and Haenszel, W.:** Statistical aspects of the analysis of data from retrospective studies of disease. *J. Nat. Cancer Inst.*, 22: 719-748, 1959.
10. **Otremski, I.; Salama, R.; Khermosh, O.; and Wientroub, S.:** An analysis of the results of a modified one-stage posteromedial release (Turco operation) for the treatment of clubfoot. *J. Pediat. Orthop.*, 7: 149-151, 1987.
11. **Ponseti, I. V.:** Current concepts review. Treatment of congenital club foot. *J. Bone and Joint Surg.*, 74-A: 448-454, March 1992.
12. **Ponseti, I. V., and Smoley, E. N.:** Congenital club foot: the results of treatment. *J. Bone and Joint Surg.*, 45-A: 261-275, 344, March 1963.
13. **Ponseti, I. V.; El-Khoury, G. Y.; Ippolito, E.; and Weinstein, S. L.:** A radiographic study of skeletal deformities in treated clubfeet. *Clin. Orthop.*, 160: 30-42, 1981.
14. **Ricciardi-Pollini, P. T.; Ippolito, E.; Tudisco, C.; and Farsetti, P.:** Congenital clubfoot: results of treatment of 54 cases. *Foot and Ankle*, 5: 107-117, 1984.
15. **Rosner, B.:** *Fundamentals of Biostatistics.* Ed. 4, pp. 370-377. Belmont, California, Duxbury Press, 1995.
16. **Simons, G. W.:** Complete subtalar release in club feet. Part II — comparison with less extensive procedures. *J. Bone and Joint Surg.*, 67-A: 1056-1065, Sept. 1985.
17. **Turco, V. J.:** Resistant congenital club foot — one-stage posteromedial release with internal fixation. A follow-up report of a fifteen-year experience. *J. Bone and Joint Surg.*, 61-A: 805-814, Sept. 1979.
18. **Vanderwilde, R.; Staheli, L. T.; Chew, D. E.; and Malagon, V.:** Measurements on radiographs of the foot in normal infants and children. *J. Bone and Joint Surg.*, 70-A: 407-415, March 1988.
19. **Wynne-Davies, R.:** Talipes equinovarus. A review of eighty-four cases after completion of treatment. *J. Bone and Joint Surg.*, 46-B(3): 464-476, 1964.

Journal of Pediatric Orthopaedics Part B
3:161–167 © 1994 Raven Press, Ltd., New York

Plaster Cast Treatment of Clubfoot: The Ponseti Method of Manipulation and Casting

José A. Morcuende, Stuart L. Weinstein, Frederick R. Dietz, and Ignacio V. Ponseti

Department of Orthopaedic Surgery, University of Iowa Hospitals and Clinics, Iowa City, Iowa, U.S.A.

Summary: We report the principles and method developed by Dr. I. V. Ponseti for correction of clubfoot. The aim of the treatment is early and full correction of all components of the deformity by gentle manipulations and well-molded plaster casts. All components of the clubfoot deformity must be corrected simultaneously, not in sequence, except for equinus, which should be corrected last. A percutaneous tendo achillis tenotomy may be needed to facilitate correction of equinus. To prevent recurrences, the corrected feet must be maintained in outward rotation in open shoes attached to a bar for many months. The results, although often not anatomically perfect, as viewed on roentgenograms, are almost perfect clinically and functionally, at least into the fifth decade of the patient's life. Key Words: Clubfoot—Ponseti method—Treatment.

Clubfoot is a complex deformity occurring in an otherwise normal child or as a part of many prenatal disorders (9). It has four components: equinus, varus, adductus, and cavus. The goal of treatment is to correct all components of the deformity so that the patient has a pain-free plantigrade foot with good mobility, without calluses, and without the need to wear modified shoes. Regardless of treatment technique, it is a difficult deformity to correct and tends to relapse.

Most orthopedists have agreed that initial treatment of a clubfoot should be nonoperative and should be instituted soon after birth (4,5,7,10,11,14, 15,18,20,24,27,29,30,32,35). In our institution, manipulations and applications of serial casts, supported by limited operative interventions, yields satisfactory long-term functional results in 89% of such feet (6,21,29,30,31). However, at other institutions, manipulative treatment has resulted in incomplete or defective corrections and distressing outcomes (2,20,24,25,27,41). To avoid these outcomes, early and even primary surgical treatment of clubfoot is practiced in some centers, often with equally disturbing failures and complications (1,2, 12–14,22,23,25,26,28,33,34,36,37,41,42). This discrepancy in the results of manipulation and serial casting suggests that the attempts at correction have been inadequate or that the technique has been faulty. In our experience, operative intervention is indicated only in the small percentage of patients who have short rigid feet, with very severe equinovarus deformity that does not respond to proper manipulations.

The success of manipulation and serial casting depends on the severity and stiffness (underlying pathology) of the deformity, age of the patient, the orthopaedists' understanding of the deformity, and their skill in appropriate manipulations and in applying plaster casts.

Although accurate assessment of the severity of the deformity at birth is commonly believed to be important, it is difficult to predict how a particular foot will respond to treatment. Sometimes an apparently stiff foot appears to become easily stretchable with manipulation, and alignment of the bones of the foot improves rapidly after application of a few casts. In other clubfeet, with use of the same technique, correction is more difficult. Invariably, a clubfoot deformity can be corrected much more easily if treatment is initiated in the first days after birth than if treatment is started after even a few weeks (8,15).

Orthopeadists must have clear understanding of the nature and degree of the deviations from normal in the tarsal and metatarsal components of the clubfoot deformity. The most severe deformities in a clubfoot occur in the hind part of the foot and are inextricably interrelated. The foot is displaced and rotated medially (adducted) beneath the talus. The talus and calcaneus are generally deformed and in severe equinus; the calcaneus is in varus and ad-

Received December 6, 1993; accepted January 31, 1994.
Address correspondence and reprints requests to Dr. Stuart L. Weinstein at Department of Orthopaedic Surgery, University of Iowa Hospitals and Clinics, Iowa City, IA 52242, U.S.A.

ducted. The cuboid is also displaced medially in front of the calcaneus. The cuneiforms are displaced downward and medially in front of the navicular, which is inverted and severely displaced. The forefoot, although adducted and inverted, is not as severely inverted as the hindfoot. As a result, the forefoot is somewhat pronated with respect to the hindfoot, and the first metatarsal is plantarflexed to a greater degree than the fifth metatarsal. It is this relation that causes the cavus deformity (19,30,32,38).

In addition, physicians must understand the functional anatomy of the normal foot, which has been best described by Huson (16,17). Without this knowledge, poorly conducted manipulations will further complicate the clubfoot deformity rather than correct it. Physicians must train their fingers to palpate the bones and joints of the foot and to feel the joint motions both in normal feet and in clubfeet. Inference of the extent of correction can be made by analysis of anteroposterior and lateral roentgenographs of the foot. Accurately determining the position of the tarsal bones is difficult, however, since most of the centers of ossification are absent at birth and may not appear for many months, or are small, slightly round, and eccentrically positioned (3,7).

The guidelines for the clubfoot treatment developed by Ponseti in the late 1940s and still followed at the University of Iowa are as follows:

1. All components of the clubfoot deformity must be corrected simultaneously, not in sequence, exception for equinus, which should be corrected last.
2. The cavus, which results from pronation of the forefoot in relation to the hindfoot, is corrected together with the adduction by supinating and abducting the forefoot in proper alignment with the hindfoot.
3. With the arch well molded and the foot in slight supination, the entire foot can be gently and gradually abducted (outward rotation) under the talus, which is secured against rotation in the ankle mortise by applying counterpressure with the thumb against the lateral part of the head of the talus. Heel varus will be corrected when the entire foot is fully abducted (never everted, but in maximum outward rotation under the talus).
4. Finally, equinus is corrected by dorsiflexing the foot. This is generally facilitated by a simple percutaneous tenotomy of the tendo achillis.
5. Well-molded plaster casts are applied after manipulations are complete.

This uniform type of treatment has been followed since 1948. More than 1,000 patients have been treated with this method, and follow-up studies of these patients attest to the soundness and success of our treatment (21,29–31). We now describe in detail the manipulative treatment and serial casting of clubfoot as well as the errors to avoid.

TREATMENT METHOD

The aim of treatment of clubfoot deformity is early and full correction of all components of the deformity by gentle manipulations and well-molded, thinly padded plaster casts, which are changed every 4–7 days. The plaster casts are applied in two sections, the first section extending from the toes to just below the knee and the second covering the knee and thigh, with the knee immobilized at a right angle. Anesthesia is never used. Early correction of all components of the deformity in the shortest possible time (usually ~2 months) is necessary for proper development of the foot, since plaster-cast treatment prolonged for many months interferes with growth and may cause further stiffness of the joints.

Because all components of the clubfoot deformity must be corrected simultaneously (except the equinus), the first manipulation and plaster cast application are intended to eliminate the cavus together with some adduction of the forefoot. The cavus is related to pronation of the forefoot with respect to the hindfoot although the entire foot is supinated because of the severe supination of the hindfoot (Fig. 1). The cavus deformity does not involve plantarflexion of equinus of the entire forefoot. Rather, there is excessive plantarflexion, primarily, of the first metatarsal (29,30). Therefore, the cavus should not be confused with forefoot equinus, which is a rare deformity consisting of a similar degree of plantarflexion in all five metatarsals.

To correct the cavus, the forefoot is gently manipulated and held in supination to place it in proper alignment with the hindfoot. An inexperienced orthopaedist may believe that the clubfoot deformity has been increased. Nevertheless, to correct the cavus, the first metatarsal must be abducted by pushing laterally on its head while the foot is in supination. In addition, forefoot adduction is also corrected by pushing laterally on the first metatarsal head (Fig. 2). This abduction entails an external rotation of the foot distal to the talus. Actually, the entire foot must be abducted under the talus, which is firmly fixed against rotation in the ankle mortise.

An attempt to correct the clubfoot deformity by forcible pronation of the entire foot increases the cavus deformity because the first metatarsal is further plantarflexed (Fig. 3). Furthermore, forefoot adduction should not be overcorrected by abducting against a thumb placed at the calcaneocuboid joint. This would prevent abduction of the calcaneus. The forefoot should not be made to angle laterally in front of the hindfoot since the hindfoot must also be abducted. Iatrogenic deformities result from attempts to correct the components of the clubfoot deformity in sequence without realizing that they are all mechanically interrelated and must be corrected simultaneously.

The plaster cast is applied to maintain the correc-

A

B

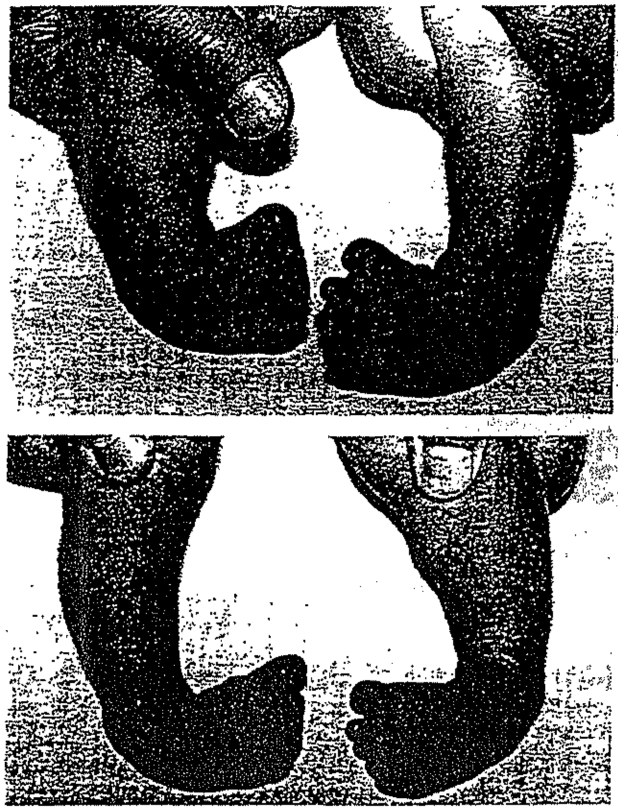


FIG. 1. Severe bilateral clubfeet in a 1-month-old infant. The heel is in severe varus and equinus; the forefoot is adducted and inverted; cavus deformity is the result of the first metatarsal being in greater plantarflexion than the other metatarsals.

tion obtained by manipulation. The first portion of the plaster cast extends to the knee and maintains the entire foot in equinus, in supination, and in slight abduction while mild counterpressure is applied over the lateral aspect of the head of the talus in front of the lateral malleolus (Fig. 4A). The plaster cast must be molded gently and with anatomic precision. After the plaster sets, the cast must be extended to the upper third of the thigh, with the knee flexed to 90° and the tibia slightly externally rotated.

Once the cavus and some adduction of the forefoot have been corrected, the metatarsals, cuneiforms, and navicular are on the same plane and form the lever arm necessary for correction of heel varus. Correction of this deformity and the severe medial displacement of the navicular necessitates more time and skill. For their proper correction, the navicular must be displaced laterally together with the cuboid and the anterior aspect of the calcaneus.

The talocalcaneal, talonavicular, and calcaneocuboid joints in a normal foot operate in strict mechanical interdependence and do not move as single hinges but rotate about a moving axis (16,17). In the clubfoot, the axes of motion of the talar joints are greatly medially displaced. Therefore, the severe tarsal displacements in the clubfoot must be corrected simultaneously by abducting the navicular, cuboid, and calcaneus under the talus before they can evert into a neutral position.

The correcting force during manipulation and casting is applied by pushing laterally over the head and shaft of the first metatarsal. Counterpressure is applied by a thumb placed on the lateral aspect of the head of the talus, which is used as a fulcrum (Fig. 2). Some orthopaedists also press medially on the posterior tuberosity of the calcaneus to ensure lateral rotation of the calcaneus under the talus. Direct forward pressure on the navicular tuberosity accomplishes little. However, even with a partially reduced navicular, the forefoot can be brought into proper alignment with the hindfoot; this is compatible with a fully functional, pain-free, plantigrade foot of normal appearance (21,29–31).

The degree of correction is best determined by placing the index finger and thumb over the medial and lateral malleolus and then moving the fingers forward to feel the head of the talus. At first, the

A

B

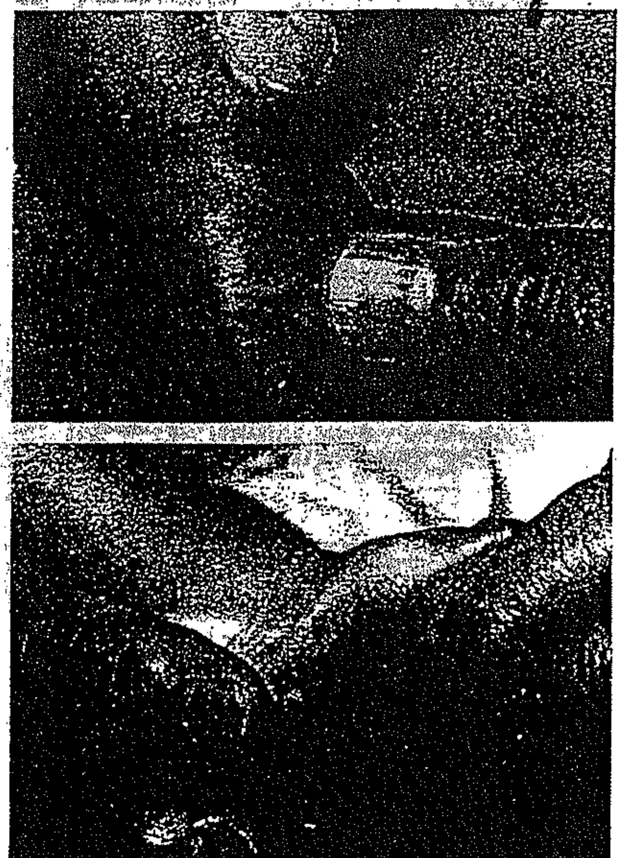


FIG. 2. Manipulative treatment. A: Thumb is positioned over the lateral aspect of the head of the talus and the fingers correct the forefoot. No counterpressure should be applied at the calcaneocuboid joint since the entire foot must be abducted under the talus. B: The cavus and adduction are corrected by slight supination of the forefoot in relation to the hindfoot. The forefoot is never everted; rather, it is displaced laterally as a unit.

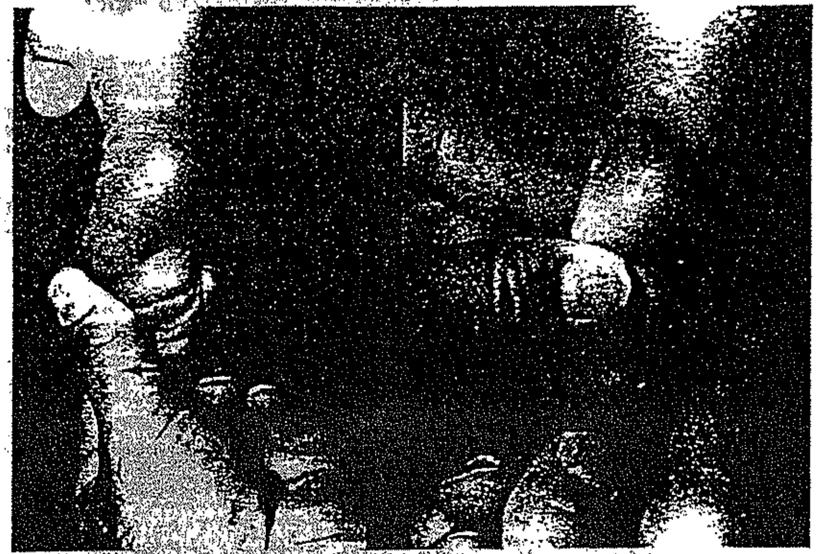
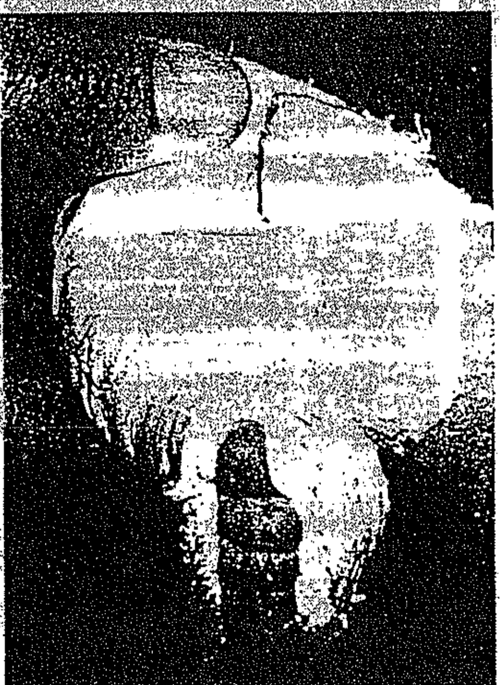


FIG. 3. In clubfoot, the entire foot is in supination but the forefoot is pronated in relation to the heel. A: Wrong maneuver of corrective manipulation. Eversion of the forefoot further plantarflexes the first metatarsal, which increases the cavus deformity and fails to correct varus of the heel. B: The foot should be corrected by outward pressure on the first metatarsal and counterpressure on the lateral aspect of the head of the talus. Correction of the severe tarsal deformities necessitates progressive lateral displacement of the navicular, cuboid, and calcaneus under the talus before they can evert into neutral position.

head of the talus is palpable on the lateral aspect of the dorsum of the foot, since the navicular is displaced inwardly. As correction progresses, when moving the foot in abduction and adduction, one can feel the navicular moving in front of the head of the talus. When the clubfoot is corrected, the lateral aspect of the talar head can no longer be palpated since it is covered by the navicular.

Correction of the severe varus deformity of the hindfoot by forcible pronation of the entire into valgus angulation is a common and harmful maneuver. This maneuver is based on the wrong assumption that the subtalar and talocalcaneonavicular joints have a fixed axis of rotation proceeding from anteromesiosuperior to posterolateroinferior, passing through the tarsal canal. The aim is to correct heel varus by everting the calcaneus on this axis, just as though the subtalar joint moved as a simple hinge. However, this maneuver fails because the calcaneus cannot tilt into valgus under the talus unless the navicular and the cuboid as well as the calcaneus are laterally displaced. Although this maneuver everts the navicular and the forefoot to some degree, it causes the inverted calcaneus to lock under the talus, thus preventing correction of the heel varus. Furthermore, an eversion or pronation twist is created in the midfoot, causing increased cavus deformity and a breach in Chopart's line (30,41).

A,B



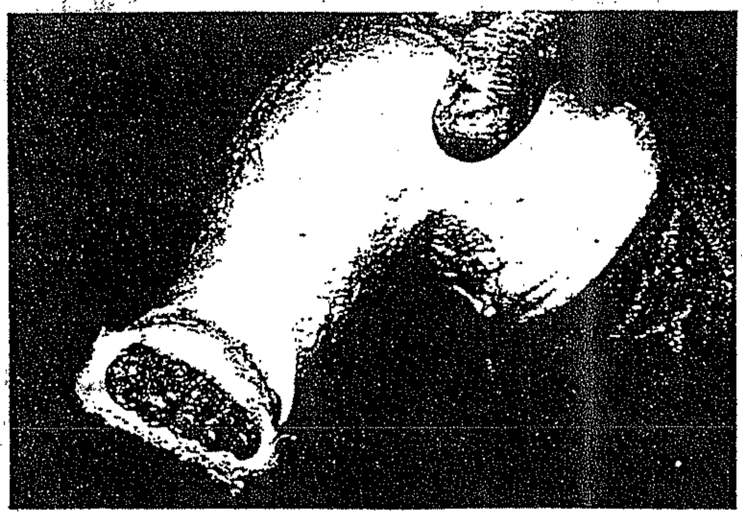


FIG. 4. Toe-to-groin, well-molded plaster casts changed weekly are used to maintain correction obtained by manipulation. A: First plaster cast is applied with the forefoot in supination in proper alignment with the hindfoot. B: With these casts, the foot can gradually be brought downward into outward rotation under the talus. Foot and leg are widely externally rotated in relation to the thigh. The sole of the foot and the toes are in a plane perpendicular to the axis of the tibia in the last plaster cast.

Excessive lateral torsion of the ankle also appears to occur if the forepart of the foot is pressed into eversion and abduction and the corrective force is transmitted to the hindfoot, which rotates laterally at the ankle joint, thus displacing the fibullar malleolus backward. This "bean-shaped" deformity is not observed when varus deformity of the heel is corrected by abduction and external rotation of the calcaneus under the talus with the foot in neutral position and not in eversion.

To prevent recurrences of the cavus deformity and a breach in midfoot, the forefoot should never be pronated. To ensure that the foot is not pronated, the plane of the metatarsal heads, which is in supination at onset of treatment, should gradually be turned into neutral position, so that in the last few plaster casts it is at a right angle to the leg. In addition, the foot can be maintained in external rotation only if the talus, ankle, and leg are stabilized by a plaster cast that extends from the toes to the upper third of the thigh with the knee flexed 90° (Fig. 4B). The talus should be firmly immobilized against rotation in the ankle mortise to force the talar head to stretch the tight plantar calcaneonavicular and talonavicular ligaments as well as the tibionavicular part of the deltoid ligament and the posterior tibial tendon. With a below-the-knee cast, the foot cannot be immobilized in firm external rotation under the talus. To insist on using short-leg casts in treatment of clubfeet is to ignore the basic role the leg and talus rotation have in the kinematics of the subtalar joint, midfoot, and forefoot.

Finally, the equinus deformity is corrected by dorsiflecting the foot after the cavus and adduction of the forefoot and the varus of the heel have been corrected. While the foot is extended with the hand flat under the entire sole of the foot, the heel is grasped with the thumb and fingers of the other hand and pulled downward. The index finger curled over the tendo achillis insertion can also exert considerable pressure downward. Care should be taken not to cause a rocker-bottom deformity, which can occur when dorsiflexion of the foot is attempted with pressure under the metatarsals rather than under the midfoot, particularly when the varus deformity of the heel has not been corrected.

A simple percutaneous tenotomy of the tendo achillis facilitates correction of the equinus. This tenotomy is indicated when 15° of dorsiflexion has not been obtained with use of casts, which is true of 95% of feet we treat. A posterior capsulotomy of the ankle and subtalar joints is rarely indicated.

Reduction of the navicular, remodeling of the naviculocuneiform joints, as well as correction of the medial angulation of the neck of the talus and correction of the varus deformity of the heel can be achieved only if the foot is held properly in abduction and external rotation in plaster casts for several weeks. Six to eight toe-to-groin plaster casts, changed weekly after proper manipulation, should be sufficient to obtain the maximum correction possible. The last plaster cast, when applied with or without a tenotomy of the tendo achillis, should be worn for 3 weeks. The last cast maintains the foot in 60°–70° of external rotation and the ankle in ~15° of dorxiflexion.

After correction of the clubfoot deformity, splinting full time for 2–3 months and at night and during the infant's naps for many months is indispensable to help prevent recurrences. Because the main corrective force of the varus and adduction is outward rotation of the foot under the talus, a splint is needed to maintain the foot in this position. This is best accomplished with the feet in well-fitted high-top shoes attached in outward rotation to a bar of about the length between the baby's shoulders. Because commercial shoes for babies do not have a molded heel, a well-countered strip of plastazote must be glued inside the counter of the shoe above the level of the baby's heel. A splint of strapping that cannot firmly maintain the foot in marked external rotation without pronation is ineffectual.

When clinical correction of the foot and the motion of the ankle are satisfactory, even though the correction may not be perfect on roentgenograms, the result of treatment is considered successful. The structural abnormalities of the talar bones and joints in a club foot cannot be fully corrected, and a completely normal foot should not be expected (18,21, 31,39,40). The aim of treatment is not to obtain an anatomically perfect foot, but a well-aligned, functional foot (Fig. 5).

With careful supervision and cooperative and responsible parents who follow instructions faithfully, relapses can be prevented in ~50% of patients (21,29). Most relapses can be treated successfully with additional manipulations and applications of casts in marked outward rotation for 4–8 weeks. This treatment is followed by lengthening of the tendo achillis if dorsiflexion of the ankle is <15°. When the anterior tibial muscle tends to supinate the foot strongly during gait, transfer of the anterior tibial tendon to the third cuneiform will prevent additional relapses in most patients. Rarely, surgical release of the tarsal joints will be necessary. This operation should not be performed at the same time as an anterior tibial transfer because it may cause very severe and difficult to correct plano valgus deformity of the foot.

Long-term results at an average of 34 years (range 25–45 years) show that 78% of the feet had excellent or good ratings (using pain and functional limitation as outcome criteria) as compared with 85% in a control population. Lower extremity length is not significantly different, but calf circumference remains smaller on the clubfoot side and the foot is shorter and narrower. All transferred anterior tibialis tendons function normally. The range of active and passive flexoextension and inversion–eversion averages 10° less than that in the normal

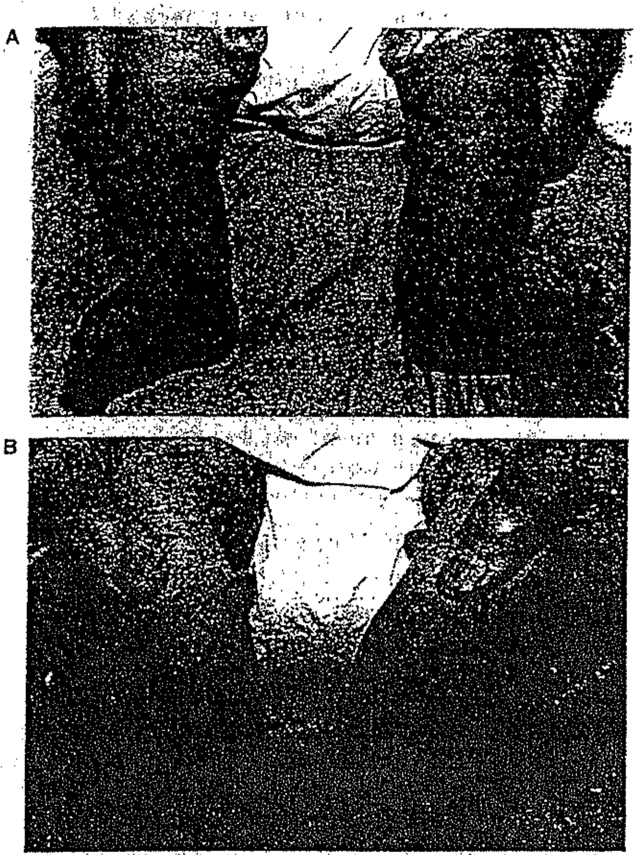


FIG. 5: Treatment result after five plaster casts (changed every week) and a percutaneous tendo achillis tenotomy. A: All components of the deformity were fully corrected. B: Complete dorsiflexion was obtained. To control relapses, well-fitting, high-topped shoes attached on a bar in 70°–80° of outward rotation are worn full time for 3 months and at night and during naps for 2 or 3 years.

feet. However, when the children walk, the clubfeet show only a few less degrees of ankle dorsiflexion, inversion–eversion, and plantarflexion than normal feet. All patients can walk on tip-toes. Mild degenerative changes were noted in 33% of clubfeet, usually on the dorsal talus, the anterior distal tibia, or the talonavicular joint. Standard radiographic measurements did not distinguish good from poor functional results within the range of radiographic values of this patient population.

Initial treatment of clubfoot should be nonoperative. Most clubfeet can be corrected in the first 2 or 3 months after birth by properly conducted manipulations and casting. A percutaneous tendo achillis tenotomy may be needed to facilitate correction of equinus. To prevent recurrences, the corrected feet must be maintained in outward rotation in open shoes attached to a bar for many months. The results, although often not anatomically perfect, as viewed on the roentgenograms, are almost perfect clinically and functionally at least into the fifth decade of the patient's life.

REFERENCES

1. Altar D, Lehman WB, Grant AD. Complications in clubfoot surgery. *Orthop Rev* 1991;20:233–9.
2. Aronson J, Puskarich CL. Deformity and disability from treated clubfoot. *J Pediatr Orthop* 1990;10:109–19.
3. Beatson TR, Pearson JR. A method of assessing correction in club feet. *J Bone Joint Surg [Br]* 1966;48:40–50.
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;10:189–92.
5. Bensahel H, Catterall A, Dimeglio A. Practical applications in idiopathic clubfoot: a retrospective multicentric study in EPOS. *J Pediatr Orthop* 1990;10:186–8.
6. Brand RA, Laaveg SJ, Crowninshield RD, Ponseti IV. The center of pressure path in treated clubfeet. *Clin Orthop* 1981; 160:43–7.
7. Carroll NC. Congenital clubfoot: pathoanatomy and treatment. *Instr Course Lect*, 1987;36:117–21.
8. Catterall A. A method of assessment of the clubfoot deformity. *Clin Orthop* 1991;264:48–53.
9. Cowell HR. Current concepts review. Genetic aspects of club foot. *J Bone Joint Surg [Am]* 1980;62:1381–7.
10. Cowell HR. The management of club foot [Editorial]. *J Bone Joint Surg [Am]* 1985;67:991–2.
11. Cummings RJ, Lovell WW. Current concepts review. Operative treatment of congenital idiopathic club foot. *J Bone Joint Surg [Am]* 1988;70:1108–12.
12. DePuy J, Drennan JC. Correction of idiopathic clubfoot: a comparison of results of early versus delayed posteromedial release. *J Pediat Orthop* 1989;9:44–8.
13. Franke J, Hein G. Our experience with early operative treatment of congenital clubfoot. *J Pediatr Orthop* 1988;8:26–30.
14. Green ADL, Lloyds-Roberts GC. The results of early posterior release in resistant club feet. A long-term review. *J Bone Joint Surg [Br]* 1985;67:588–93.
15. Harrold AJ, Walker CJ. Treatment and prognosis in congenital clubfoot. *J Bone Joint Surg [Br]* 1983;65:8–11.
16. Huson A. *Een Ontleedkundig-Functioneel Onderzoek van de Voetwortel.* Leiden: Proefschrift, 1961.
17. Huson A. Functional anatomy of the foot. In: Jahss MH, ed. *Disorders of the foot and ankle.* Philadelphia: W.B. Saunders, 1991:409–31.
18. Hutchings PM, Foster BK, Paterson DC, Cole EA. Long-term results of early surgical release in clubfeet. *J Bone Joint Surg [Br]* 1985;67:791–9.
19. Ippolito E, Ponseti IV. Congenital club foot in human fetus. A histological study. *J Bone Joint Surg [Am]* 1980;62:8–22.
20. Karski T, Wosko I. Experience in the conservative treatment of congenital clubfoot in newborns and infants. *J Pediatr Orthop* 1989;9:134–6.
21. Laaveg SJ, Ponseti IV. Long-term results of treatment of congenital clubfoot. *J Bone Joint Surg [Am]* 1980;62:23–31.
22. Lau JHK, Meyer LC, Lau HC. Results of surgical treatment of talipes equinovarus congenita. *Clin Orthop* 1989;248:219–26.
23. Levin MN, Kuo KN, Harris GF, Matesi DV. Posteromedial release for idiopathic talipes equinovarus. A long-term follow-up study. *Clin Orthop* 1989;242:265–8.
24. Lovell WW, Bailey T, Price CT, Purvis JM. The nonoperative management of the congenital clubfoot. *Orthop Rev* 1979;8:113–5.
25. Main BJ, Crider RJ. An analysis of residual deformity in club feet submitted to early operation. *J Bone Joint Surg [Br]* 1978;60:536–43.
26. Miller JH, Bernstein SM. The roentgenographic appearance of the "corrected clubfoot." *Foot Ankle* 1986;6:177–83.
27. Nather A, Bose K. Conservative and surgical treatment of clubfoot. *J Pediatr Orthop* 1987;7:42–8.
28. Otremski I, Salama R, Khermosh O, Wientroub KM. An analysis of the results of a modified one-stage posteromedial release (Turco operation) for the treatment of clubfoot. *J Pediatr Orthop* 1987;7:149–51.

29. Ponseti IV, Smoley EN. Congenital clubfoot: the results of treatment. *J Bone Joint Surg [Am]* 1963;45:261–75.
30. Ponseti IV, Campos J. Observations on pathogenesis and treatment of congenital clubfoot. *Clin Orthop* 1972;84:50–60.
31. Ponseti IV, El-Khoury GY, Ippolito E, Weinstein SL. A radiographic study of skeletal deformities in treated clubfeet. *Clin Orthop* 1981;160:30–42.
32. Ponseti IV. Current concepts review. Treatment of congenital club foot. *J Bone Joint Surg [Am]* 1992;74:448–54.
33. Pous JG, Dimeglio A. Neonatal surgery in club foot. *Orthop Clin North Am* 1978;9:233–40.
34. Ryöppy S, Sairanen H. Neonatal operative treatment of club foot. A preliminary report. *J Bone Joint Surg [Br]* 1983;65:320–5.
35. Seringe R, Atia R. Idiopathic congenital talipes equinovarus. *Rev Chir Orthop* 1990;76:490–501.
36. Simons GW. Complete subtalar release in clubfeet. Part II—comparison with less extensive procedures. *J Bone Joint Surg [Am]* 1985;67:1056–65.
37. Somppi E, Sulamaa M. Early operative treatment of congenital club foot. *Acta Orthop Scand* 1971;42:513–20.
38. Thompson GH, Richardson AB, Westin GW. Surgical management of resistant congenital talipes equinovarus deformities. *J Bone Joint Surg [Am]* 1982;64:652–65.
39. Turco VJ. Resistant congenital club foot—one stage posteromedial release with internal fixation. A follow-up report of a fifteen-year experience. *J Bone Joint Surg [Am]* 1979;61:805–14.
40. Vigliani F. Codivilla's operation after seventy years. *Ital J Orthop and Traumatol* 1975;1:297–313.
41. Wynne-Davis R. Talipes equinovarus. A review of eighty-four cases after completion of treatment. *J Bone Joint Surg [Br]* 1964;46:464–76.

Current Concepts Review

Treatment of Congenital Club Foot

BY IGNACIO V. PONSETI, M.D.*, IOWA CITY, IOWA

Investigation performed at the Department of Orthopaedic Surgery, University of Iowa Hospitals and Clinics, Iowa City

Congenital club foot is a complex deformity that is difficult to correct. It has a tendency to recur until the age of six or seven years. While there may be a so-called recurrence in an adolescent, this is usually associated with incomplete correction rather than being secondary to growth alone. The deformity has four components: equinus, varus, adductus, and cavus. The goal of treatment is to reduce or eliminate these four deformities so that the patient has a functional, pain-free, plantigrade foot, with good mobility and without calluses, and does not need to wear modified shoes. A postural varus foot, which is commonly noted at birth, is easily corrected into a normal foot with manipulation, if it does not correct on its own in a few weeks. A postural varus foot is not a club foot.

The most severe deformities in a club foot occur in the hind part of the foot. The talus and calcaneus are generally deformed and in severe equinus, the calcaneus is in varus angulation and medially rotated, and the navicular is severely displaced medially[5,7,15,19,35,53]. These components of the deformity are inextricably interrelated. The ligaments of the posterior aspect of the ankle and of the medial and plantar aspects of the foot are shortened and thickened. The muscles and tendons of the gastrocnemius, tibialis posterior, and toe flexors are shortened[25,44,53,66].

Most orthopaedists have agreed that the initial treatment of a club foot should be non-operative. The preferred method is manipulation and application of a plaster cast at weekly intervals[8,11,12,17,23,27,33,36,41,45,50,55,63,66,68,72]. Less favored methods of initial treatment are use of a Denis Browne splint, stretching and adhesive strapping, and physiotherapy[4,18,34,70]. All of these methods can be successful when they have been applied properly, although incomplete or defective correction may be common.

Although it is important to assess the severity of the deformity at birth, it is difficult to predict how the foot will respond to manipulation. The success of manipulation and serial application of casts varies with the age of the patient, the severity of the deformity, the skill of the orthopaedist, and the orthopaedist's understanding of the deformity. In some club feet, apparently tight ligaments seem to become easily stretchable with manipulation, and the alignment of the bones of the foot improves rapidly after the application of a few casts. In other club feet, the primary osseous deformities and tight ligaments resist correction. Invariably, it is much easier to correct a club-foot deformity in the first days of life than after even a few weeks[10,18,47,48].

Manipulation and serial application of casts, supported by limited operative intervention, yielded satisfactory functional results in 89 per cent of the feet in our clinic[30]. However, at other institutions, manipulative treatment has resulted in increased cavus deformity, rocker-bottom deformity, a longitudinal breach, flattening of the proximal surface of the talus, lateral rotation of the ankle, and increased stiffness of the ligaments and joints[2,27,29,33,38,41,54,62,69].

To avoid these distressing outcomes, early and even primary operative treatment of club foot is practiced in some centers, often with equally disturbing failures and complications, such as wound infection, necrosis of the skin, severe scarring, stiff joints, overcorrection and undercorrection, dislocation of the navicular, flattening and beaking of the talar head, talar necrosis, and weakness of the plantar flexors of the ankle with major disturbances of gait[1,2,31,32,38,40,52,55,58,69,72]. The reported results of operations in newborns have been either short term or not encouraging[16,17,31,49,51,60]. Early operative treatment often results in reduced motion of the ankle and foot, whereas manipulation and the application of plaster casts with proper technique leads to greater mobility and less disability[2,29]. Some people believe, as I do, that "the successful non-operatively treated club foot is much better than the successful surgically treated foot"[59]. Most orthopaedists have agreed that an operation should be considered only after manipulation and serial application of casts have failed to obtain correction in a specified period of time, preferably not more than three months.

The poor results of manipulative treatment of most club feet in many clinics suggest that the attempts at correction have been inadequate or that the technique has been faulty. Books and papers on pediatric orthopaedics have devoted scant space to manipulative technique in the treatment of this deformity, and often the descriptions have been incorrect. The correction of the cavus

*Department of Orthopaedic Surgery, University of Iowa Hospitals and Clinics, Iowa City, Iowa 52242.

component of the deformity is usually not addressed[8]. The cavus deformity does not involve plantar flexion or equinus of the entire fore part of the foot. Rather, there is excessive plantar flexion, primarily of the first and second metatarsals. Lateral roentgenograms of club feet often show the fifth metatarsal to be well aligned with the cuboid and calcaneus, whereas the first metatarsal is in severe plantar flexion[44,45,66]. Therefore, although the entire foot appears to be supinated because of the severe supination of the hind part of the foot, the fore part of the foot is pronated with respect to the hind part, as a result of the cavus deformity. This deformity is thus the result of the first metatarsal being in more plantar flexion than the fifth metatarsal[43-45].

The cavus deformity must be corrected with the first cast. Since the cavus deformity is related to pronation of the fore part of the foot with respect to the hind part, it is corrected by placement of the fore part of the foot in supination in proper alignment with the hind part. An attempt to correct the inversion of the foot by forcible pronation of the anterior part of the foot increases the cavus deformity as the first metatarsal is plantar-flexed further[44,45]. Unfortunately, in most reports, photographs have shown the fore part of the foot held in pronation in the plaster cast[9,63,65]. The cavus deformity remains uncorrected in this situation. In fact, the cavus component tends to increase when the fore part of the foot is immobilized in pronation with respect to the hind part of the foot.

Whereas cavus and adduction deformities of the fore part of the foot of infants yield easily to proper manipulation, correction of the varus deformity of the heel and the severe medial displacement of the navicular necessitate more time and skill. In many clinics, correction of the severe varus deformity of the hind part of the foot is attempted with forcible pronation of the whole foot into valgus angulation. This maneuver fails because the calcaneus cannot tilt into valgus angulation under the talus unless it is laterally rotated. Forceful pronation of the foot is a common and harmful maneuver because it increases the cavus deformity, causes a breach in the mid-part of the foot, and does not correct the varus deformity of the heel. In contrast to rocker-bottom foot, which represents a break around the transverse axis, a breach in the mid-part of the foot can take place around a sagittal axis when the foot is forcefully pronated while the heel is in varus angulation. It seems that the ligaments of the mid-part of the foot yield to the force directed toward pronation of the foot, and the mid-part of the foot is wrenched into pronation until the foot is plantigrade while the hind part of the foot remains uncorrected[45,62,69].

For proper correction of the varus deformity of the hind part of the foot, it is necessary to displace the navicular laterally together with the cuboid and the anterior aspect of the calcaneus. Once the cavus has been corrected, the metatarsals, cuneiforms, and navicular are on the same plane and form the lever arm that is necessary for this lateral displacement. The lateral shift of the navicular, the cuboid, and the calcaneus in relationship to the talus will be possible when the tight joint capsules and ligaments on the inner aspect of the foot yield gradually to manipulation, before the plaster cast is applied. This abduction or lateral shift entails an external rotation of the foot distal to the talus[22,36,45]. A thumb that is placed on the lateral aspect of the head of the talus is used as a fulcrum. The foot can be maintained in external rotation only if the talus, the ankle, and the leg are stabilized by a plaster cast that extends from the toes to the groin, with the knee flexed 90 degrees. A below-the-knee cast cannot immobilize the foot in firm external rotation under the talus[8,9,33]. To prevent recurrence of the cavus deformity and a breach in the mid-part of the foot, the foot should never be pronated. Rather, it must be abducted and externally rotated. To ensure that the foot is not pronated, the plane of the metatarsal heads, which is in supination at the onset of treatment, should be gradually turned into a neutral position, so that it is at a right angle to the leg, in the last few plaster casts. The plane of the metatarsal heads should never be turned into pronation[44,45].

Complete reduction of the extreme medial displacement of the navicular is not possible with manipulation in most severe club feet. Direct forward pressure on the navicular tuberosity accomplishes little[63]. The calcaneonavicular ligament, the tibionavicular ligament, and the posterior tibial tendon cannot be stretched sufficiently to position the navicular properly. Even if the navicular were freed by cutting of the ligaments, the deformed contour of the talar head would be inadequate to accommodate it[56]. Therefore, rather than the medial ligaments being cut, they should be stretched, as much as they will yield, by firm abduction of the fore part of the foot[30]. With a partially reduced navicular, the fore part of the foot can be brought into proper alignment with the hind part, because the ligaments in front of the navicular yield and allow lateral displacement and lateral angulation of the cuneiforms with respect to the navicular[14,46]. The cuboid falls into normal position with respect to the anterior tuberosity of the calcaneus. The anterior aspect of the calcaneus should be laterally displaced and rotated enough to correct the varus deformity of the heel. Some orthopaedists also press medially on the posterior tuberosity of the calcaneus to ensure lateral rotation of the calcaneus under the talus[36,57,63]. The partial reduction of the navicular, the remodeling of the navicular-cuneiform joints in abduction as well as the correction of the medial angulation of the neck of the talus, and the correction of the varus deformity of the heel can be achieved only if the foot is held properly in severe abduction and external rotation in plaster casts for several weeks and in a Denis Browne splint for a long time.

Various degrees of relative medial tibial torsion may be associated with club foot[24,28], and the deformity will persist if below-the-knee casts are used for treatment[9,33,71].

Tibial torsion, varus deformity of the heel, and adduction of the foot can be gradually corrected if toe-to-groin plaster casts are applied with the knee flexed 90 degrees and the foot laterally rotated[30]. The leg portion of the cast, which includes the foot, should be held in lateral rotation while the thigh portion hardens[45]. Excessive lateral torsion of the ankle seems to occur if the fore part of the foot is "pressed into eversion and abduction" and "the corrective force is transmitted to the hindfoot which ... rotates laterally at the ankle joint, thus displacing the fibular malleolus backwards"[62]. This bean-shaped deformity[38] is not observed when varus deformity of the heel is corrected by abduction and external rotation of the calcaneus under the talus with the foot in a neutral position and not in eversion[30,46]. Placement of the thumb on the lateral aspect of the head of the talus prevents the talus from rotating laterally in the ankle joint.

The equinus is corrected by dorsiflexion of the foot with the heel in valgus after the adduction of the foot and the varus deformity of the heel have been corrected. The correction entails stretching of the tight posterior capsules and ligaments of the ankle and subtalar joints and the tendo achillis[20,21,25]. Two or three plaster casts that carefully mold the heel, applied after manipulation, are usually needed to correct the equinus deformity. Care should be taken not to cause a rocker-bottom deformity, which can occur when dorsiflexion of the foot is attempted with pressure under the metatarsals rather than under the mid-part of the foot, particularly when the varus deformity of the heel has not been corrected[33,45,63]. A simple subcutaneous tenotomy of the tendo achillis, performed with the patient under local anesthesia, facilitates correction of the equinus[30,45]. This tenotomy is done in about 70 per cent of patients, when 15 degrees of dorsiflexion has not been obtained with the use of the casts. Dorsiflexion of the ankle to more than 10 to 15 degrees is rarely possible because of the talar and calcaneal malformations and tight ligaments[20,23,30,38,54]. A posterior capsulotomy of the ankle and subtalar joint is rarely done, because the few additional degrees of correction that are obtained may be completely lost later due to retraction of the scar tissue[2,17,23,55].

Six to eight toe-to-groin plaster casts, changed weekly after proper manipulation and worn for seven to ten weeks, should be sufficient to obtain the maximum correction possible[16,30,45]. The last plaster cast, which should be applied after a tenotomy of the tendo achillis if the tendon is short and prevents dorsiflexion of the ankle of at least 15 degrees, is worn for three weeks. The cast maintains the foot in 50 to 60 degrees of external rotation, to ensure correction of the varus deformity of the hind part of the foot and correction of the adduction of the foot, and maintains the ankle in about 15 degrees of dorsiflexion[44,45].

After the last plaster cast has been removed, the degree of correction is evaluated clinically. An experienced clinician can evaluate, by palpation, the position of the navicular in relation to the head of the talus, the position of the cuboid in relation to the anterior tuberosity of the calcaneus, the positions of the heel and of the fore part of the foot in relation to the hind part of the foot, and the range of movement of the ankle.

The degree of correction of the deformity can also be inferred from an analysis of anteroposterior and lateral roentgenograms of the foot. However, it is difficult to estimate the accurate position of the tarsal bones because the centers of ossification are small and eccentrically positioned and the navicular does not ossify until the age of two or three years[9,56]. It is important to understand that a talocalcaneal angle that is at some variance from the normal range does not signify a poor clinical result[9,30,66].

When the clinical correction of the foot and the motion of the ankle are satisfactory, even though the correction may not be perfect on roentgenograms, the result of treatment should be considered successful. The structural abnormalities of the talar bones and joints in a club foot cannot be corrected fully, and a completely normal foot should not be expected[20,23,30,46,63,66,68].

Regardless of treatment, a club-foot deformity tends to relapse until the child is about seven years old. To prevent relapse, some orthopaedists hold the foot in maximum correction with a series of plaster casts or with splints. Denis Browne splints and high-top shoes with well molded heels that hold the feet in lateral rotation are the most effective means for maintenance of the correction[23,30,45]. The splints are worn full time for two to three months and thereafter at night for two to four years. The splint should maintain the foot in 60 to 70 degrees of external rotation, to prevent recurrence of varus deformity of the heel, adduction of the foot, and in-toeing. The ankle should be in dorsiflexion, to prevent equinus, and this is accomplished by bending of the splint with the convexity of the bar directed distally. A splint or strapping that cannot firmly maintain the foot in marked external rotation without forced pronation is ineffectual[18,34]. The added advantage of a Denis Browne splint compared with a fixed splint is that it allows some motion of the foot and ankle. Ordinary high-top shoes should be used for walking for two to three years, as they provide good stability for the ankle. Although outflare shoes and lateral wedges are recommended by many orthopaedists[63], they are unnecessary if the foot has been corrected well and they are ineffectual if the foot has not been corrected.

With careful supervision and cooperative and responsible parents who follow instructions faithfully, relapse can be prevented in about 50 per cent of patients. In the other 50 per cent, a relapse will occur between the ages of ten months and seven years (average age, two and one-half years)[30,45]. A relapse is detected when slight equinus and varus deformity of the heel is observed, usually without increased cavus and adduction deformity of the fore part of the foot. The original correction may be recovered in four to eight weeks with manipulations followed by application of a toe-to-groin plaster cast, with the foot held in marked lateral rotation, every ten to fourteen days. This treatment is often followed by lengthening of the tendo achillis, if the tendon prevents dorsiflexion of the ankle to at least 15 degrees, and by use of the Denis Browne splint at night.

To prevent more relapses, the tendon of the anterior tibial muscle is transferred to the third cuneiform if this muscle tends to supinate the foot strongly after correction has been obtained[26,29,45]. The anterior tibial muscle has a strong supinatory action when the abnormal relationship between the talus and the calcaneus has not been corrected fully, as indicated by smaller talocalcaneal angles. My clinical experience indicates that, in a large proportion of club feet that are treated with this procedure, the correction of the varus deformity of the heel that was obtained with manipulation and application of casts can be maintained and the anteroposterior talocalcaneal angle will become normal[30]. The transferred anterior tibial tendon dorsiflexes the foot in neutral position without supination. However, transfer of the tendon does not correct the lateral talocalcaneal angle, which indicates that there is residual restriction of motion of the subtalar joint and of dorsiflexion of the ankle. People who have a club foot generally cannot dorsiflex the ankle to much more than 10 to 15 degrees and, as a consequence, they do not begin heel-strike as far posteriorly as people who have normal feet[6].

My experience has been that the cavus component of the club-foot deformity rarely recurs[30,46]. When this deformity is resistant to manipulation, it should be treated with plantar fasciotomy and recession of the extensor hallucis longus tendon to the neck of the first metatarsal[30,45].

The adductus component of the club-foot deformity does not recur in patients who have received good treatment and follow-up care[30,46].

When proper treatment with manipulation and casts has been started shortly after birth, operative release of the tarsal joints seldom is needed[27,29,30,70]. An early operation (not later than the second month of life) is indicated only in the small percentage of patients who have short, rigid feet, with very severe equinovarus deformity, that do not respond to proper manipulations. Many orthopaedists also favor release of the tarsal joints in less rigid feet when manipulations have failed to completely correct the displacement of the navicular and the talocalcaneal alignment to a normal talocalcaneal index.

Many operations have been employed to accomplish this correction since the beginning of the twentieth century[7,23,36,57,65,67]. Extensive posteromedial release, with or without internal fixation of the tarsal bones, is the preferred procedure[1,2,16,31,32,64,65], but there has been much disagreement about the timing of the operation[13,16,17,23,39,42]. More satisfactory results have been reported when the operation is delayed until the child is nearly one year old[65]. With good operative technique, most resistant club feet can be corrected satisfactorily with an extensive posteromedial release, with functional results that are almost as good as those obtained with the manipulative method[16,23,42,55,64,65]. Less-good results, with more complications, have been reported by surgeons who used similarly extensive procedures as well as less extensive operations[1,2,17,31,32,40,52,71,72]. It appears that "limited subtalar arthrotomy is not as effective as complete subtalar release in obtaining lasting correction"[72].

Recently, more radical techniques have been tried in younger patients[36,49,57,58]. The objective of all of these operations is release of the tight capsules and ligaments of the ankle and tarsal joints and lengthening of the shortened tendons of the foot to facilitate placement of the tarsal bones in normal alignment. Since the distorted joints are no longer congruent, the new position of the bones often has to be secured with internal fixation, usually Kirschner wires, and with plaster casts that are worn for several months. The reduction may look good roentgenographically, but when the wires are removed the bones are stabilized in the new positions only by the formation of scar tissue, which presents the prospect of increasing stiffness. Furthermore, there is always the risk of overcorrection and displacement of the navicular. Of course, extensive operative treatment is necessary to correct more severe deformities. Whether the joints will remodel to allow a functional range of motion of the foot and ankle will be known only after long-term follow-up has established whether the added operative procedure improves functional results[11,37,58].

In my experience, 85 to 90 per cent of club feet have been treated successfully with proper manipulation and applications of casts, tenotomy of the tendo achillis and transfer of the anterior tibial tendon when indicated, and careful supervision[30]. A well corrected club foot appears normal; is mobile, painless, and functional; and is only about one centimeter shorter than the normal foot. The circumference of the calf may be two centimeters smaller than that of the contralateral calf, but usually the legs are of normal length and without torsional deformities. However, motion of the ankle and subtalar joints is somewhat restricted[30]. The size and configuration of the bones retain some of the characteristics that they exhibited at birth[20,23,25,46,53]. The medial angulation of the talar neck corrects as the adduction is corrected, whereas the navicular may become more wedge-shaped[46]. The medial displacement of the navicular and the talocalcaneal index may be only partially corrected, but the fore part of the foot is aligned properly with the hind part of the foot, the heel is in neutral position, and the footprint, center-of-pressure path, and gait are virtually normal[6,30].

In summary, the goal of treatment of congenital club foot is a functional, pain-free, plantigrade foot, with good mobility and without calluses, that does not necessitate the wearing of modified shoes. The initial treatment of club foot should be non-operative. Corrective manipulation and serial application of casts, followed by calcaneal tenotomy and transfer of the anterior tibial tendon if indicated, should be successful in at least 85 per cent of patients who are initially treated a few days after birth. The orthopaedist must have a thorough understanding of the deformity and be highly skilled with regard to manipulation and the application of plaster casts. The main components of this type of treatment are as follows.

1. The cavus deformity is corrected by supination of the fore part of the foot with respect to the hind part.

2. The varus deformity of the hind part of the foot is corrected with displacement or lateral rotation of the navicular, together with the cuboid and the anterior aspect of the calcaneus, without pronation of the foot. Attempts to correct the varus deformity of the hind part of the foot with forcible pronation of the whole foot into valgus angulation is harmful because it causes an increase in the cavus deformity and a breach in the midpart of the foot and does not correct the varus deformity of the heel.

3. Maintenance of the correction of the varus deformity of the hind part of the foot entails marked external rotation of the foot distal to the talus. This is accomplished by a toe-to-groin plaster cast with the knee flexed 90 degrees and the foot in maximum external rotation. A below-the-knee cast cannot immobilize the foot in firm external rotation.

4. The equinus is corrected last, by dorsiflexion of the foot with the heel in valgus angulation. A subcutaneous tenotomy of the tendo achillis, performed with the patient under local anesthesia, facilitates correction of the equinus. The last plaster cast, which often is applied after a tenotomy of the tendo achillis, is applied with the foot in at least 60 degrees of external rotation and the ankle in 15 degrees of dorsiflexion. The total duration of treatment should be less than three months.

5. To maintain the correction, a Denis Browne splint on shoes in 60 degrees of external rotation and in dorsiflexion should be worn full time for three months and at night for two to four years.

6. Most relapses can be treated successfully with additional manipulations and applications of casts for four to eight weeks. When the anterior tibial muscle tends to supinate the foot strongly, a transfer of the anterior tibial tendon to the dorsum of the foot will prevent additional relapses in most patients.

Operative correction of a club foot is indicated when the deformity has not been treated successfully with proper manipulation and serial application of casts, supported by limited operative intervention. Most of these resistant club feet can be corrected with the use of an extensive posteromedial release, with satisfactory functional results.

The deformities of the bones and joints are rarely, if ever, corrected completely. Some persistent medial displacement of the navicular bone and a talocalcaneal index that is outside of the normal range are compatible with a fully functional, normal-looking, pain-free, plantigrade foot.

References

1. **Altar, Dan; Lehman, W. B.;** and **Grant, A. D.:** Complications in clubfoot surgery. *Orthop. Rev.*, 20: 233-239, March 1991.
2. **Aronson, James,** and **Puskarich, C. L.:** Deformity and disability from treated clubfoot. *J. Pediat. Orthop.*, 10: 109-119, 1990.
3. **Beatson, T. R.,** and **Pearson, J. R.:** A method of assessing correction in club feet. *J. Bone and Joint Surg.*, 48-B(1): 40-50, 1966.
4. **Bensahel, H.; Guillaume, A.; Czukonyi, Z.;** and **Desgrippes, Y.:** Results of physical therapy for idiopathic clubfoot: a long-term follow-up study. *J. Pediat. Orthop.*, 10: 189-192, 1990.
5. **Bissell, J. B.:** The morbid anatomy of congenital talipes equino-varus. *Arch. Pediat.*, 5: 406-418, 1888.
6. **Brand, R. A.; Laaveg, S. J.; Crowninshield, R. D.;** and **Ponseti, I. V.:** The center of pressure path in treated clubfeet. *Clin. Orthop.*, 160: 43-47, 1981.
7. **Brockman, E. P.:** *Congenital Club-Foot (Talipes Equinovarus).* Bristol, John Wright, 1930.
8. **Carroll, N. C.:** Congenital clubfoot: pathoanatomy and treatment. In *Instructional Course Lectures, The American Academy of Orthopaedic Surgeons.* Vol. 36, pp. 117-121. Park Ridge, Illinois, The American Academy of Orthopaedic Surgeons, 1987.
9. **Carroll, Norris:** Clubfoot. In *Lovell and Winter's Pediatric Orthopaedics*, edited by R. T. Morrissy. Ed. 3, vol. 2, pp. 927-956. Philadelphia, J. B. Lippincott, 1990.
10. **Catterall, Anthony:** A method of assessment of the clubfoot deformity. *Clin. Orthop.*, 264: 48-53, 1991.
11. **Cowell, H. R.:** The management of club foot [editorial]. *J. Bone and Joint Surg.*, 67-A: 991-992, Sept. 1985.
12. **Cummings, R. J.,** and **Lovell, W. W.:** Current concepts review. Operative treatment of congenital idiopathic club foot. *J. Bone and Joint Surg.*, 70-A: 1108-1112, Aug. 1988.
13. **DePuy, Jim,** and **Drennan, J. C.:** Correction of idiopathic clubfoot: a comparison of results of early versus delayed posteromedial release. *J. Pediat. Orthop.*, 9: 44-48, 1989.
14. **Evans, Dillwyn:** Relapsed club foot. *J. Bone and Joint Surg.*, 43-B(4): 722-733, 1961.
15. **Fahrenbach, G. J.; Kuehn, D. N.;** and **Tachdjian, M. O.:** Occult subluxation of the subtalar joint in clubfoot (using computerized tomography). *J. Pediat. Orthop.*, 6: 334-339, 1986.
16. **Franke, Jürgen,** and **Hein, Günter:** Our experiences with the early operative treatment of congenital clubfoot. *J. Pediat. Orthop.*, 8: 26-30, 1988.
17. **Green, A. D. L.,** and **Lloyd-Roberts, G. C.:** The results of early posterior release in resistant club feet. A long-term review. *J. Bone and Joint Surg.*, 67-B(4): 588-593, 1985.
18. **Harrold, A. J.,** and **Walker, C. J.:** Treatment and prognosis in congenital club foot. *J. Bone and Joint Surg.*, 65-B(1): 8-11, 1983.
19. **Herzenberg, J. E.; Carroll, N. C.; Christofersen, M. R.; Lee, E. H.; White, Steve;** and **Munroe, Robert:** Clubfoot analysis with three-dimensional computer modeling. *J. Pediat. Orthop.*, 8: 257-262, 1988.
20. **Hjelmstedt, Åke,** and **Sahlstedt, Bo:** Talar deformity in congenital clubfeet. An anatomical and functional study with special reference to the ankle joint mobility. *Acta Orthop. Scandinavica*, 45: 628-640, 1974.

21. **Hosking, S. W.,** and **Scott, W.:** A study of the anatomy and biomechanics of the ankle region in normal and club feet (talipes equino varus) of infants. *J. Anat.*, 134 (Part 2): 227-236, 1982.
22. **Huson, Anthony:** *Een Ontleedkundig-Functioneel Onderzoek van de Voetwortel.* Leiden, Proefschrift, 1961.
23. **Hutchins, P. M.; Foster, B. K.; Paterson, D. C.;** and **Cole, E. A.:** Long-term results of early surgical release in club feet. *J. Bone and Joint Surg.*, 67-B(5): 791-799, 1985.
24. **Hutchins, P. M.; Rambicki, D.; Comacchio, L.;** and **Paterson, D. C.:** Tibiofibular torsion in normal and treated clubfoot populations. *J. Pediat. Orthop.*, 6: 452-455, 1986.
25. **Ippolito, Ernesto,** and **Ponseti, I. V.:** Congenital club foot in the human fetus. A histological study. *J. Bone and Joint Surg.*, 62-A: 8-22, Jan. 1980.
26. **Ippolito, E.; Ricciardi-Pollini, P. T.; Tudisco, C.;** and **Ronconi, P.:** The treatment of relapsing clubfoot by tibialis anterior transfer underneath the extensor retinaculum. *Italian J. Orthop. and Traumatol.*, 11: 171-177, 1985.
27. **Karski, Tomasz,** and **Wosko, Ignacy:** Experience in the conservative treatment of congenital clubfoot in newborns and infants. *J. Pediat. Orthop.*, 9: 134-136, 1989.
28. **Krishna, M.; Evans, R.; Sprigg, A.; Taylor, J. F.;** and **Theis, J. C.:** Tibial torsion measured by ultrasound in children with talipes equinovarus. *J. Bone and Joint Surg.*, 73-B(2): 207-210, 1991.
29. **Kuhlmann, R. F.,** and **Bell, J. F.:** A clinical evaluation of operative procedures for congenital talipes equinovarus. *J. Bone and Joint Surg.*, 39-A: 265-283, April 1957.
30. **Laaveg, S. J.,** and **Ponseti, I. V.:** Long-term results of treatment of congenital club foot. *J. Bone and Joint Surg.*, 62-A: 23-31, Jan. 1980.
31. **Lau, J. H. K.; Meyer, L. C.;** and **Lau, H. C.:** Results of surgical treatment of talipes equinovarus congenita. *Clin. Orthop.*, 248: 219-226, 1989.
32. **Levin, M. N.; Kuo, K. N.; Harris, G. F.;** and **Matesi, D. V.:** Posteromedial release for idiopathic talipes equinovarus. A long-term follow-up study. *Clin. Orthop.*, 242: 265-268, 1989.
33. **Lovell, W. W.; Bailey, Thomas; Price, C. T.;** and **Purvis, J. M.:** The nonoperative management of the congenital clubfoot. *Orthop. Rev.*, 8: 113-115, Aug. 1979.
34. **Lusskin, Ralph:** The technique of dynamic adhesive strapping for congenital clubfoot. *Bull. Hosp. Joint Dis.*, 47: 235-244, 1987.
35. **McKay, D. W.:** New concept of and approach to clubfoot treatment: section I — principles and morbid anatomy. *J. Pediat. Orthop.*, 2: 347-356, 1982.
36. **McKay, D. W.:** New concept of and approach to clubfoot treatment: section II — correction of the clubfoot. *J. Pediat. Orthop.*, 3: 10-21, 1983.
37. **McKay, D. W.:** New concept of and approach to clubfoot treatment: section III — evaluation and results. *J. Pediat. Orthop.*, 3: 141-148, 1983.
38. **Main, B. J.,** and **Crider, R. J.:** An analysis of residual deformity in club feet submitted to early operation. *J. Bone and Joint Surg.*, 60-B(4): 536-543, 1978.
39. **Main, B. J.; Crider, R. J.; Polk, M.; Lloyd-Roberts, G. C.; Swann, Malcolm;** and **Kamdar, B. A.:** The results of early operation in talipes equino-varus. A preliminary report. *J. Bone and Joint Surg.*, 59-B(3): 337-341, 1977.
40. **Miller, J. H.,** and **Bernstein, S. M.:** The roentgenographic appearance of the "corrected clubfoot." *Foot and Ankle*, 6: 177-183, 1986.
41. **Nather, A.,** and **Bose, K.:** Conservative and surgical treatment of clubfoot. *J. Pediat. Orthop.*, 7: 42-48, 1987.
42. **Otremski, I.; Salama, R.; Khermosh, O.;** and **Wientroub, S.:** An analysis of the results of a modified one-stage posteromedial release (Turco operation) for the treatment of clubfoot. *J. Pediat. Orthop.*, 7: 149-151, 1987.
43. **Paulos, Lonnie; Coleman, S. S.;** and **Samuelson, K. M.:** Pes cavovarus. Review of a surgical approach using selective soft-tissue procedures. *J. Bone and Joint Surg.*, 62-A: 942-953, Sept. 1980.
44. **Ponseti, I. V.,** and **Campos, Jeronimo:** Observations on pathogenesis and treatment of congenital clubfoot. *Clin. Orthop.*, 84: 50-60, 1972.
45. **Ponseti, I. V.,** and **Smoley, E. N.:** Congenital club foot: the results of treatment. *J. Bone and Joint Surg.*, 45-A: 261-275, 344, March 1963.
46. **Ponseti, I. V.; El-Khoury, G. Y.; Ippolito, Ernesto;** and **Weinstein, S. L.:** A radiographic study of skeletal deformities in treated clubfeet. *Clin. Orthop.*, 160: 30-42, 1981.
47. **Porter, R. W.:** Congenital talipes equinovarus: I. Resolving and resistant deformities. *J. Bone and Joint Surg.*, 69-B(5): 822-825, 1987.
48. **Porter, R. W.; Roy, A.;** and **Rippstein, J.:** Assessment in congenital talipes equinovarus. *Foot and Ankle*, 11: 16-21, 1990.
49. **Pous, J.-G.,** and **Dimeglio, Alain:** Neonatal surgery in clubfoot. *Orthop. Clin. North America*, 9: 233-240, 1978.
50. **Ricciardi-Pollini, P. T.; Ippolito, Ernesto; Tudisco, Cosimo;** and **Farsetti, Pasquale:** Congenital clubfoot: results of treatment of 54 cases. *Foot and Ankle*, 5: 107-117, 1984.
51. **Ryöppy, S.,** and **Sairanen, H.:** Neonatal operative treatment of club foot. A preliminary report. *J. Bone and Joint Surg.*, 65-B(3): 320-325, 1983.
52. **Schlafly, Bruce; Butler, J. E.; Siff, S. J.; Criswell, A. R.;** and **Cain, T. E.:** The appearance of the tarsal navicular after posteromedial release for clubfoot. *Foot and Ankle*, 5: 222-237, 1985.
53. **Schlicht, David:** The pathological anatomy of talipes equino-varus. *Australian and New Zealand J. Surg.*, 33: 1-11, 1963.
54. **Scott, W. A.; Hosking, S. W.;** and **Catterall, A.:** Club foot. Observations on the surgical anatomy of dorsiflexion. *J. Bone and Joint Surg.*, 66-B(1): 71-76, 1984.
55. **Seringe, R.; Bonvin, J. C.; Miladi, L.;** and **Fassier, F.:** Traitement chirurgical du pied bot varus équin congénital idiopathique par libération des parties molles. *Rev. chir. orthop.*, 72 (supplement 2): 63-65, 1986.
56. **Shapiro, Frederic,** and **Glimcher, M. J.:** Gross and histological abnormalities of the talus in congenital club foot. *J. Bone and Joint Surg.*, 61-A: 522-530, June 1979.
57. **Simons, G. W.:** Complete subtalar release in club feet. Part I — a preliminary report. *J. Bone and Joint Surg.*, 67-A: 1044-1055, Sept. 1985.
58. **Simons, G. W.:** Complete subtalar release in club feet. Part II — comparison with less extensive procedures. *J. Bone and Joint Surg.*, 67-A: 1056-1065, Sept. 1985.
59. **Simons, G. W.:** Correspondence. *J. Bone and Joint Surg.*, 68-A: 151-152, Jan. 1986.
60. **Somppi, E.,** and **Sulamaa, M.:** Early operative treatment of congenital club foot. *Acta Orthop. Scandinavica*, 42: 513-520, 1971.
61. **Sutherland, D. H.; Cooper, Les;** and **Daniel, Dale:** The role of the ankle plantar flexors in normal walking. *J. Bone and Joint Surg.*, 62-A: 354-363, April 1980.

62. **Swann, Malcolm; Lloyd-Roberts, G. C.; and Catterall, A.:** The anatomy of uncorrected club feet. A study of rotation deformity. *J. Bone and Joint Surg.*, 51-B(2): 263-269, 1969.
63. **Tachdjian, M. O.:** *The Child's Foot.* Philadelphia, W. B. Saunders, 1985.
64. **Thompson, G. H.; Richardson, A. B.; and Westin, G. W.:** Surgical management of resistant congenital talipes equinovarus deformities. *J. Bone and Joint Surg.*, 64-A: 652-665, June 1982.
65. **Turco, V. J.:** Resistant congenital club foot — one-stage posteromedial release with internal fixation. A follow-up report of a fifteen-year experience. *J. Bone and Joint Surg.*, 61-A: 805-814, Sept. 1979.
66. **Turco, V. J.:** *Clubfoot.* New York, Churchill Livingstone, 1981.
67. **Vigliani, F.:** Codivilla's operation after seventy years. *Italian J. Orthop. and Traumatol.*, 1: 297-313, 1975.
68. **Westin, G. W.:** Clubfoot: where to stop the wheel. *Contemp. Orthop.*, 19: 235-249, 1989.
69. **Wynne-Davies, Ruth:** Talipes equinovarus. A review of eighty-four cases after completion of treatment. *J. Bone and Joint Surg.*, 46-B(3): 464-476, 1964.
70. **Yamamoto, Haruyasu,** and **Furuya, Kohtaro:** Treatment of congenital club foot with a modified Denis Browne splint. *J. Bone and Joint Surg.*, 72-B(3): 460-463, 1990.
71. **Yngve, D. A.:** Foot-progression angle in clubfeet. *J. Pediat. Orthop.*, 10: 467-472, 1990.
72. **Yngve, D. A.; Gross, R. H.; and Sullivan, J. A.:** Clubfoot release without wide subtalar release. *J. Pediat. Orthop.*, 10: 473-476, 1990.