Radiographic Evaluation of Idiopathic Clubfeet Undergoing Ponseti Treatment

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Background: The Ponseti method for treatment of idiopathic clubfeet involves the use of serial casts, percutaneous Achilles tenotomy in most cases, and bracing with an abduction orthosis to prevent relapse. Although Ponseti recommended evaluation of the infant clubfoot strictly by palpation, many orthopaedic surgeons still rely on radiographs for decision-making during treatment. The aim of this study was to document with radiographs the effect of percutaneous Achilles tenotomy as described by Ponseti.

Methods: We conducted a study of idiopathic clubfeet treated, at two centers, with the Ponseti method, including percutaneous Achilles tenotomy. Cast treatment was started within three weeks after birth, and radiographs were made before and after the tenotomy. Lateral radiographs with the foot in maximal dorsiflexion at the ankle were made for all patients, and anteroposterior radiographs of the foot were made at one center. The lateral tibiocalcaneal angle, the anteroposterior talocalcaneal angle, and the lateral talocalcaneal angle were measured on the radiographs. Foot dorsiflexion at the ankle was evaluated clinically. The results from both centers were evaluated separately and in combination.

Results: Lateral dorsiflexion radiographs that showed the foot and ankle were evaluated for eighty-seven clubfeet, and anteroposterior radiographs that showed the foot were evaluated for sixty-five clubfeet. The mean improvement in the lateral tibiocalcaneal angle after the tenotomy was 16.9°. The mean change in the anteroposterior talocalcaneal angle was 2.1°, and the mean change in the lateral talocalcaneal angle change was 1.4°. The mean increase in clinically measured dorsiflexion after the tenotomy (in sixty-five feet) was 15.1°. Only the lateral tibiocalcaneal angle and dorsiflexion as measured clinically changed significantly after the Achilles tenotomy ($p < 0.05$). When the results at each center were analyzed separately, they were found to be nearly identical.

Conclusions: The increase in the lateral tibiocalcaneal angle after Achilles tenotomy is essentially the same as the increase in ankle dorsiflexion seen on clinical examination. The anteroposterior and lateral talocalcaneal angles are not influenced significantly by the tenotomy. Radiographs confirmed that the additional dorsiflexion obtained from the percutaneous Achilles tenotomy is true dorsiflexion occurring in the ankle and hindfoot and not in the midfoot.

Level of Evidence: Therapeutic Level IV. See Instructions to Authors for a complete description of levels of evidence.

Disclosure: The authors did not receive any outside funding or grants in support of their research for or preparation of this work. Neither they nor a member of their immediate families received payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity. No commercial entity paid or directed, or agreed to pay or direct, any benefits to any research fund, foundation, division, center, clinical practice, or other charitable or nonprofit organization with which the authors, or a member of their immediate families, are affiliated or associated.

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Idiopathic clubfoot deformity is the most common musculoskeletal birth defect in Western countries. The foot is typically in equinus and cavus positions, with the hindfoot in varus and internally rotated and the forefoot adducted[1]. The etiology is still unknown, and treatment recommendations vary, although all authors have agreed that the initial treatment should include application of casts. Traditionally, the cast was changed weekly for several months, after which an extensive open surgical procedure was done to correct any residual deformity. The reported rates of successful correction of clubfeet with the traditional method of cast treatment without surgery ranged from 15% to 61%[2-6]. Ponseti reported avoiding extensive open surgery in 89% of cases with his technique of manipulation, cast treatment, and limited, percutaneous surgery[7,8], and a growing number of pediatric orthopaedic surgeons have adopted the Ponseti method for the treatment of idiopathic congenital clubfeet, with good results[9-13].

The Ponseti method consists of weekly manipulation and application of casts. The initial casts correct the cavus deformity by supinating the forefoot and dorsiflexing the first metatarsal, thereby aligning the forefoot with the hindfoot. To correct the varus and adduction, the supinated foot is abducted while counterpressure is applied with the thumb against the head of the talus. In the final cast, 70° of foot abduction must be obtained[8]. In the majority of cases, a percutaneous Achilles tenotomy is performed, after application of about five to nine casts, to correct the residual equinus deformity. Ponseti did not recommend the standard use of radiographs; instead, he suggested that palpation alone should be employed to assess correction[8]. Ultrasound to study infant clubfoot deformity has been described in the recent literature[14-17] but is not yet routinely used clinically. Many orthopaedic surgeons still rely on radiographs when trying to assess the correction before or after tenotomy and to detect subtle midfoot changes that would point to the development of a rocker-bottom deformity. The aim of our study was to describe the radiographic appearance of infant clubfeet before and after treatment with a percutaneous Achilles tenotomy as part of the Ponseti method and to determine the amount of correction achieved by the tenotomy.

Materials and Methods

We have applied the Ponseti treatment regimen, strictly as originally described by Ponseti[8], from 2002 at the Department of Pediatric Orthopaedics, Orthopaedic Hospital Speising-Vienna (Center 1) and from 1997 at the Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore (Center 2).

In 2002, a prospective study protocol was started at Center 1. Most referrals of patients with clubfoot to our institution were from obstetrics departments. Criteria for inclusion in the study were (1) congenital clubfoot treated with the Ponseti method, including a percutaneous Achilles tenotomy; (2) the initiation of cast treatment within three weeks after birth; (3) foot radiographs made within two days before the tenotomy; and (4) foot radiographs made within one week after cast removal (within three weeks after the tenotomy).

In Center 1, an anteroposterior radiograph of the foot and a lateral radiograph of the foot and ankle with the foot in maximum dorsiflexion, as described by Simons[18], are made for all infants with clubfoot. The radiographic cartridge is positioned by the x-ray technician and is held in position by the parent or legal guardian of the infant or by one of us. The lateral tibiocalcaneal angle, the anteroposterior talocalcaneal an-

TABLE I Mean Values, in Degrees, with the Standard Error and Standard Deviation for Each Variable Measured in the Patients at Center 1

Angle (N = 65)	Mean	Std. Error	Std. Deviation
Lateral tibiocalcaneal angle			
Before tenodesis	84.69	1.56	12.58
After tenodesis	68.85	1.48	11.91
Change	15.85	1.45	11.67
Lateral talocalcaneal angle			
Before tenodesis	34.98	1.89	15.25
After tenodesis	36.35	1.37	11.01
Change	1.37	1.24	10.03
Anteroposterior talocalcaneal angle			
Before tenodesis	29.06	1.47	11.89
After tenodesis	31.15	1.21	9.74
Change	2.09	1.07	8.61
Dorsiflexion			
Before tenodesis	13.46	1.35	10.89
After tenodesis	28.57	1.05	8.46
Change	15.11	1.22	9.87

TABLE II Mean Values, in Degrees, with the Standard Error and Standard Deviation for Each Variable Measured in the Patients at Center 2

Angles (N = 22)	Mean	Std. Error	Std. Deviation
Lateral tibiocalcaneal angle			
Before tenodesis	88.45	2.71	12.7
After tenodesis	68.36	2.3	10.8
Change	20.09	1.68	7.88
Lateral talocalcaneal angle			
Before tenodesis	35.36	2.41	11.28
After tenodesis	36.95	2.53	11.87
Change	1.59	1.9	8.91

gle, and the lateral talocalcaneal angle were evaluated by one of us (C.R.). The maximum foot dorsiflexion was assessed clinically with a handheld goniometer by the attending orthopaedic surgeon.

The clubfeet were classified at the time of presentation with use of the systems of Dimeglio et al.[19] and Pirani et al.[20]. The percutaneous Achilles tenotomy was always performed in the operating room at Center 1. A local anesthetic in combination with a sedative with monitoring by an anesthesiologist was used in the initial cases, and general anesthesia was used later.

The patient population treated at Center 2 since 2004 was reviewed retrospectively, and the inclusion criteria were (1) congenital clubfoot treated with the Ponseti method, including a percutaneous Achilles tenotomy; (2) cast treatment started within three weeks after birth; (3) foot radiographs made within seven days before the Achilles tenotomy; (4) and radiographs made after the Achilles tenotomy.

Only lateral radiographs—usually printout from the image intensifier—were made at this center. The percutaneous Achilles tenotomies were done in the orthopaedic clinic with use of local anesthesia and the parents or legal guardians present.

The study protocols were approved by both institutional review boards, and the parents or legal guardians of all patients provided informed consent.

All values were recorded on a standard form, and statistical analysis was performed with use of SPSS for Windows (SPSS, Chicago, Illinois). Descriptive statistical analysis and testing for normal distribution with use of the Kolmogorov-Smirnov test were performed for both groups. As all data sets showed a normal distribution, a two-tailed t test was used for significance testing. The results from the two centers were analyzed separately, and the mean values were compared. In a second analysis, all cases were analyzed as one patient group. In addition, we analyzed the correlation between the classifications of the clubfeet treated at Center 1, derived with the systems of Dimeglio et al.[19] and Pirani et al.[20], and the evaluated parameters.

Results

Forty-four patients with a total of sixty-five clubfeet were included prospectively in the Center-1 study protocol. There were thirty-three male and eleven female patients. The clubfoot deformity was bilateral in twenty-one patients and unilateral in the remaining twenty-three. The mean age at the time when the first cast was applied was six days (range, one to twenty days). The mean Dimeglio score was 9.6 points (range, 5 to 15 points), and the mean Pirani score was 3.9 points (range, 2 to 6 points). The mean age when the Achilles tenotomy was performed was nine weeks (range, five to seventeen weeks).

The lateral tibiocalcaneal angle improved by an average of 15.9° after the tenotomy in the patients in Center 1. The an-

TABLE III Mean Values, in Degrees, with the Standard Error and Standard Deviation for Each Variable Measured in the Patients at Both Centers

Angles (N = 87)	Mean	Std. Error	Std. Deviation
Lateral tibiocalcaneal angle			
Before tenodesis	85.64	1.36	12.64
After tenodesis	68.72	1.24	11.58
Change	16.92	1.17	10.95
Lateral talocalcaneal angle			
Before tenodesis	35.08	1.53	14.29
After tenodesis	36.51	1.2	11.17
Change	1.43	1.04	9.71

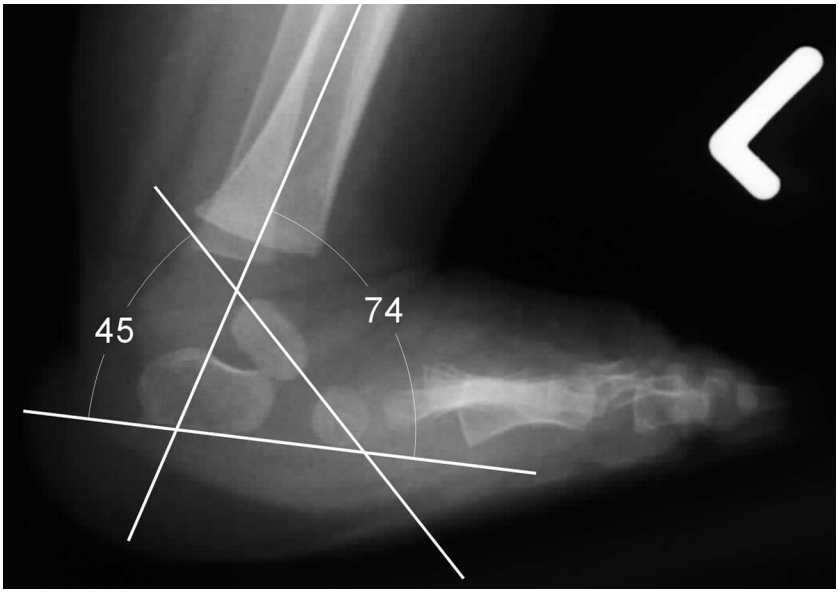

Fig. 1-A

A lateral radiograph of the foot and ankle, made before the percutaneous Achilles tenotomy, shows a tibiocalcaneal angle of 74° despite foot dorsiflexion of 24° on clinical examination. In this patient with pseudocorrection, a percutaneous Achilles tenotomy was performed and the last cast was applied in mild dorsiflexion with molding of the foot arch and the calcaneocuboid joint.

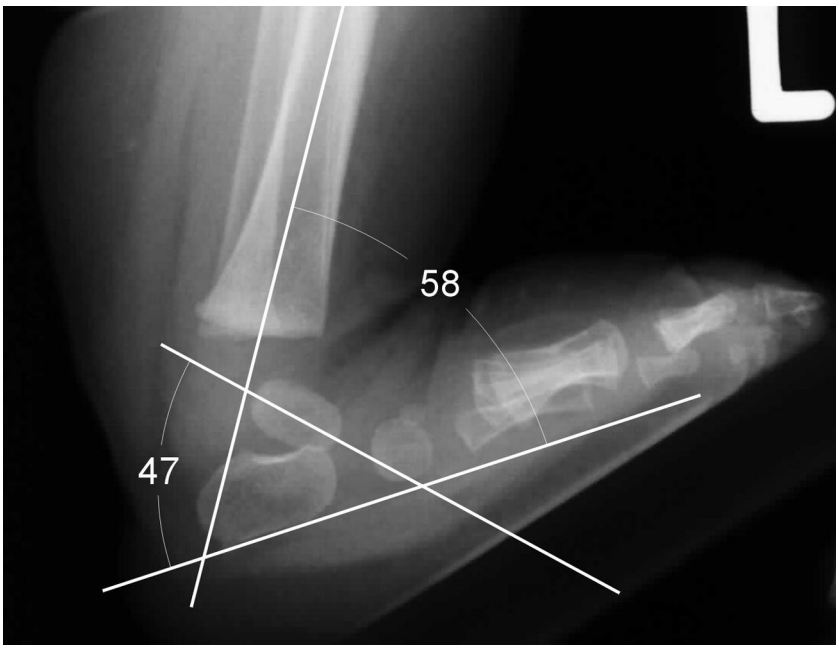

Fig. 1-B

A lateral radiograph of the foot and ankle, made after removal of the cast three weeks later, shows that the lateral tibiocalcaneal angle has decreased and the pseudocorrection that had occurred previously is improved in the midfoot.

teroposterior talocalcaneal angle changed by a mean of 2.1°, and the lateral talocalcaneal angle changed by a mean of 1.4°. The mean improvement in the dorsiflexion measured at the clinical examination was 15.1°. All mean values, with the standard deviation and standard error, are given in Table I.

Fourteen patients with a total of twenty-two clubfeet met the inclusion criteria of the retrospective study protocol at Center 2. There were ten male and four female patients. The clubfoot was bilateral in eight patients and unilateral in the remaining six. The mean age at the time when the first cast was

applied was ten days (range, one to twenty-one days). The mean age when the percutaneous Achilles tenotomy was performed, with use of local anesthesia in the clinic, was eight weeks (range, six to ten weeks).

In the Center-2 case series, the lateral tibiocalcaneal angle improved by an average of 20° after the tenotomy, and the mean change in the lateral talocalcaneal angle was 1.6°. All mean values, with the standard deviation and standard error, are given in Table II.

The results of the descriptive statistical analysis of the data from both centers combined are summarized in Table III. For comparison of means, the two case series were analyzed as one data set. After a standard distribution was confirmed with use of the Kolmogorov-Smirnov test, a paired-samples t test was used to compare the variables before and after the Achilles tenotomy. The t test showed no significant post-tenotomy change in the anteroposterior or lateral talocalcaneal angle ($p > 0.05$), whereas the lateral tibiocalcaneal angle and the clinical measurement of dorsiflexion at the ankle changed significantly ($p < 0.01$).

An analysis of the correlation of the Pirani and Dimeglio scores with the evaluated radiographic and clinical parameters showed a positive Pearson correlation coefficient (0.251), significant at the 0.05 level, between the Pirani score and the lateral tibiocalcaneal angle before the tenotomy and a positive Pearson correlation coefficient (0.310), significant at the 0.05

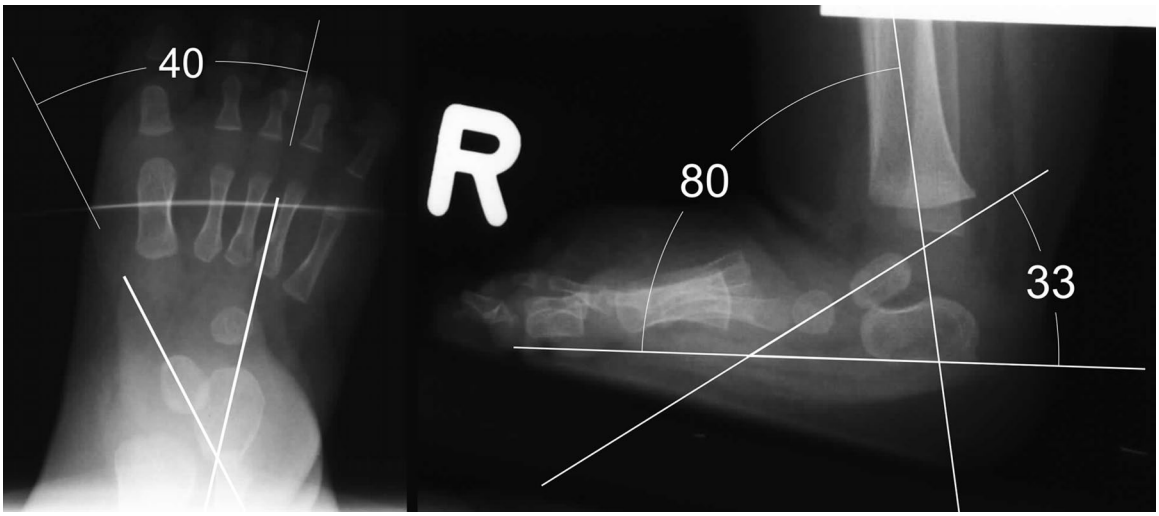

Fig. 2-A

Anteroposterior and lateral radiographs of the foot of an infant who had 5° of dorsiflexion on clinical examination showed a tibiocalcaneal angle of 80° before the tenotomy.

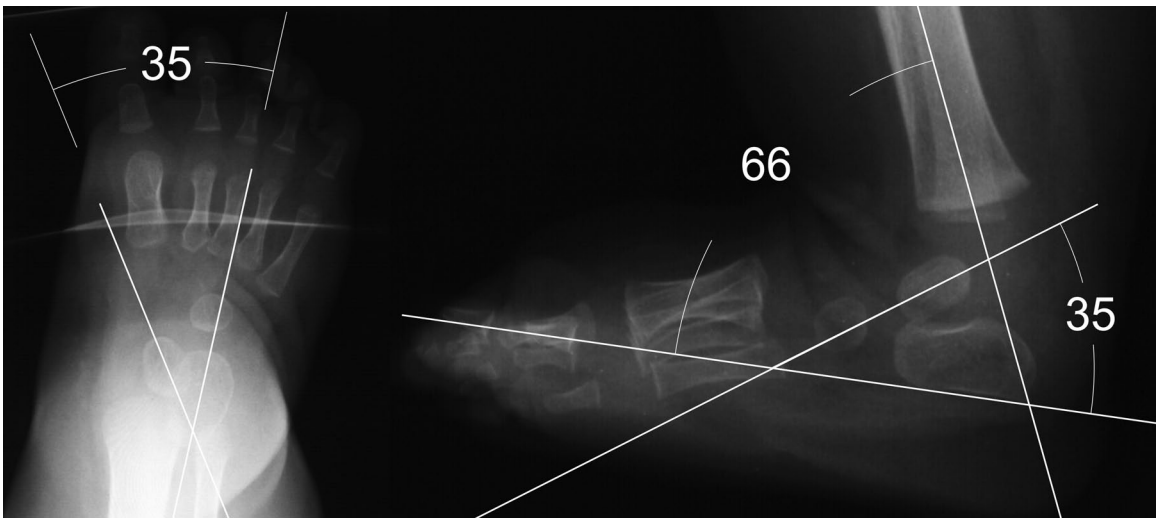

Fig. 2-B

Three weeks after the tenotomy, anteroposterior and lateral radiographs of the foot revealed a 14° decrease in the lateral tibiocalcaneal angle, whereas the lateral and anteroposterior talocalcaneal angles showed only minimal changes.

level, between the Dimeglio score and the lateral tibiocalcaneal angle before the tenotomy. With the numbers studied, none of the other tested variables showed a significant correlation with the Pirani or Dimeglio score.

Seven feet had good clinical dorsiflexion despite a high lateral tibiocalcaneal angle (Figs. 1-A and 1-B). Partial pseudocorrection, or a mild rocker-bottom deformity, with dorsiflexion in the midfoot was noted on the lateral radiographs of these feet, and a percutaneous Achilles tenotomy was performed despite the measurement of >15° of dorsiflexion clinically. The last cast used after the tenotomy was applied in only mild dorsiflexion with molding of the plantar arch. The pseudocorrection was reversed in all but one of these feet, in which the pseudocorrection decreased but was still present on the radiograph after the tenotomy.

Discussion

One of the key elements of the Ponseti method for the treatment of congenital clubfeet is the percutaneous Achilles tenotomy. It is used to correct the residual equinus position of the foot after the cavus, hindfoot varus, forefoot adduction, and inversion have been corrected with the casts. Ponseti reported performing a tenotomy in about 85% of his patients[8]. Fifteen degrees of ankle dorsiflexion should be obtained with the tenotomy for sufficient clubfoot correction. The tenotomy is indicated when dorsiflexion of at least 15° cannot be obtained at the clinical examination. Ponseti relied on clinical examination and palpation and used radiographs only in unusual cases.

Unfortunately, radiographic measurements in the infant foot are not fully reliable. Simons stated that "considerable controversy exists concerning the use of radiographic techniques in the evaluation of clubfeet" in 1978 and discussed the absence or small size of ossification centers in young children[21]. Nevertheless, he noted that angle variance due to minor errors in positioning and to movement of the infant's foot is relatively small. Howard and Benson showed that the size, position, and alignment of the ossific nuclei in the talus and calcaneus in clubfeet are different from those in normal feet and that radiographs do not reflect the true deformity, especially underestimating equinus in the lateral projection[22]. The relationship of the ossific nucleus to the overlying cartilage has been described in more detail in a three-dimensional computed tomographic study[1].

The quality of radiographs is partially dependent on the manner in which the foot is held on the film-plate. Additionally, there is a bias in the drawing of the lines to represent the axes of ossific nuclei, which often appear almost circular at this very young age, when the angles are measured. For many years, radiographs have routinely been made for infant clubfeet at our institutions, and the radiology technicians perform these studies accurately. In most cases, the radiographs were made under our direct supervision. The fact that the results from the two centers are within such a close range further emphasizes the value of the statistical analysis and the reliability of the presented data.

Our results indicate that the changes in the lateral tibiocalcaneal angle after Achilles tenotomy are essentially the same as the changes in dorsiflexion as measured clinically. The anteroposterior and lateral talocalcaneal angles were not influenced significantly by the Achilles tenotomy in this series (Figs. 2-A and 2-B), which is expected, since lengthening of the Achilles tendon mainly affects the calcaneus. The dorsal opening of the talocalcaneal joint represented by an increase of the lateral talocalcaneal angle is coupled with derotation of the talus and calcaneus on the anteroposterior radiograph represented by an increase in the anteroposterior talocalcaneal angle, as noted by Ponseti[8], Simons[18], and Bösch[23]. With the Ponseti method, the anteroposterior talocalcaneal angle should be corrected before performance of the percutaneous Achilles tenotomy, which is done only after the calcaneus has been fully rotated (abducted) out from under the neck and head of the talus[8].

The mean value of 13.46° of dorsiflexion of the foot at the ankle found on clinical examination before the tenotomy in Center 1 may seem relatively high, and some may argue that a tenotomy was not necessary in some of these cases. However, this mean value is the result of three factors. First, it includes the values for the seven feet with pseudocorrection, in which dorsiflexion of 20° to 32° was present before the tenotomy despite the presence of a high lateral tibiocalcaneal angle. Second, when the Ponseti method was introduced in Center 1, there were often delays in obtaining an appointment for the tenotomy in the operating room due to logistic reasons. If the tenotomy is not performed as soon as the foot can be abducted to 70° and all of the deformities except the equinus are corrected, prolonged cast immobilization may lead to a mild increase in dorsiflexion. As a result, many of the patients treated early in Center 1 had dorsiflexion of 5° to 15° before the tenotomy. Finally, the only cases in which we do not perform a tenotomy are those with dorsiflexion of >15° and a lateral tibiocalcaneal angle that is seen to be well corrected on radiographs. When the equinus has not been fully corrected, we expect mild recurrence, with loss of dorsiflexion leading to problems with wearing of the orthosis, a subsequent decline in compliance with orthotic use, and further relapse as a sequel. The Achilles tenotomy has been reported to be a safe and minimally invasive procedure[24], and we think that it is justifiable to perform it in all other cases.

In the normal feet of infants, the anteroposterior talocalcaneal angle has been reported to range from 15° to 55°; the lateral talocalcaneal angle, from 25° to 55°; and the lateral tibiocalcaneal angle, from 25° to 60°[21,25]. Compared with these values, our results suggest that mild residual equinus was found in most of our patients. Only fourteen feet in this series had a lateral tibiocalcaneal angle of <60° after the tenotomy, whereas only four feet showed dorsiflexion of <15° on clinical examination. The lateral talocalcaneal angle was outside of the reported normal range (lower limit, 25°) in only twelve feet in our series. The anteroposterior talocalcaneal angle was within the reported range in all but two feet, in which the values were <15°.

Pseudocorrection, or a mild and early form of rocker-bottom deformity, is the result of passive dorsiflexion of the foot against the contracted Achilles tendon before the tenotomy, in the period in which the casts are applied. This iatro-

genic deformity is shown radiographically by forced-foot-dorsiflexion views when the midfoot dorsiflexes excessively in relation to the hindfoot. Performing radiographic studies before a decision is made to perform an Achilles tenotomy may help to detect this pseudocorrection. As an alternative to radiographs, a thorough clinical inspection and palpation may reveal an empty heel pad and a high-rising posterior tuberosity of the calcaneus.

The correlation of the Pirani and Dimeglio scores before treatment with the lateral tibiocalcaneal angle before the tenotomy may be a sign that the position of the calcaneus before the tenotomy accurately reflects the severity of the hindfoot deformity. The Pirani and Dimeglio classifications help to objectify the severity of clubfeet and make it possible to compare results from different series; therefore, all clubfeet should be assessed with these classifications prior to treatment.

An issue for discussion may be the exposure of infants to radiation. Radiographic assessment of an infant's clubfoot in Center 1 involved 40 kV at 3.2 mAs, resulting in 0.37 (mGy). In comparison, an anteroposterior pelvic radiograph (58 kV at 5.6 mAs) results in 2.69 mGy and the radiation is administered nearer to radiation-sensitive organs. Thus, we believe that the benefits of the additional information provided by radiographic assessment of clubfeet outweigh the risk of radiation exposure. The image-intensifier printouts used in Center 2 resulted in even less radiation exposure.

Radiographs may not be useful for assessing the exact amount of correction, and the surgeon should be aware of this limitation when evaluating the radiographs of clubfeet of infants. We do not recommend the standard use of multiple radiographs during treatment of clubfeet with the Ponseti method. Nevertheless, radiographs are helpful in certain cases to determine the need for an Achilles tenotomy and to detect pseudocorrection so that it can be treated with a tenotomy to ensure sufficient correction before the bracing period. If pseudocorrection is detected, a cast should be reapplied with the foot in some amount of equinus and should be worn for a week or two to allow the plantar ligaments to tighten, after which the percutaneous Achilles tenotomy should be done. ■

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