Original Article

Dynamic Adduction Angle of Forefoot Measured With a Novel Technique And Its Relationship With Functional Outcomes

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Abstract

Background: **Idiopathic clubfoot is commonly treated with the Ponseti method with the extent of invasive treatment involving tendon-Achilles lengthening. Forefoot adduction is a common complication in surgically treated clubfeet. Yet, no method has been described to measure dynamic (walking) forefoot adduction. The aim of this study was to assess the persistent *pes adductus* in children whose clubfeet were surgically treated using a dorsomedial soft tissue release and to find out correlations between forefoot adduction and clinical outcome measures.**

Methods: **We analysed the dynamic adduction angle in 33 clubfeet using a pressure-sensitive foot platform and compared it to the healthy feet of an age- and weight-matched group of children without congenital foot deformities. The clinical outcome was analysed using the McKay score.**

Results: **Mean dynamic adduction angle was 4.10 in the surgically corrected clubfeet, whereas it was 6.4° in unaffected feet of patients with unilateral clubfoot and 7.10 in control group. The McKay score were excellent in 1 patient, good in 5, average in 13, and fair in 4 of the 23 patients. There was no correlation between dynamic adduction angle and McKay score using paired t test (*P* > 0.05).**

Conclusion: **High occurrence of dynamic adduction angle in surgically treated clubfeet was detected. In conclusion, no correlation between forefoot adduction, dynamic forefoot adduction angle and clinical outcome measures within the study was observed.**

Keywords: *clubfoot, congenital talipes equinovarus, equinovarus, talipes equinovarus*

Introduction

Idiopathic congenital talipes equinovarus (CTEV), also known as congenital idiopathic clubfoot, is a pediatric foot deformity involving four major components: ankle equinus, hindfoot varus, forefoot in adduction, and midfoot cavus (1). Multiple treatment regimens have been used to treat clubfoot including splinting, plaster casting, surgical procedures involving medial, posterior, and lateral releases, osteotomies, and arthrodesis (2–4). Success in curing clubfoot was variable (1,5–7) until Ponseti (1) reviewed more than 50 years of data indicating that initial non-operative treatment of clubfoot is desirable regardless of the severity of the deformity (8-11).

Current treatment procedures favor the Ponseti method with the extent of "surgery" being tendon-Achilles lengthening before application of the final cast. For resistant clubfeet or failed Ponseti, the la carte surgical approach is preferred to the full posteromedial release method employed previously (1). Although treatment options vary based on the surgeon's preference, the common goal of treatment is to reduce or eliminate all components involved, in order to obtain pain-free, plantigrade, pliable, and cosmetically and functionally acceptable feet irrespective of treatment type, (surgical or conservative), recurrence of forefoot adduction is the most commonly seen complications (1). We have developed a novel technique to measure the forefoot adduction while walking, also known as dynamic forefoot adduction. In this method, we measured the frequency of persistent *pes adductus* in children whose clubfeet were surgically treated using a dorsomedial soft tissue release and we sought correlations between forefoot adduction and clinical outcome measures.

Materials and Methods

Thirty-three patients (all newborn babies on first day of life) who had a primary clubfoot and who had undergone a surgical posteromedial release at one institution (pediatric orthopedic hospital) between 1994 and 2000 were analysed in a retrospective study. Forty-three congenital clubfeet were included. All patients had been treated as infants at the institution of their birth for an idiopathic congenital clubfoot. The parents of the infants gave their informed consent prior to their inclusion in the study. The exclusion criterion was any child who had a known neuromuscular or genetic abnormality leading to the clubfoot.

All children in the study were treated with a long leg cast applied within 24 hours of birth. Each child further underwent treatment with series of plaster casts before ultimately undergoing dorsomedial release as described by Turco (13).

Twenty-three out of 33 (77%) clubfeet children were included in the follow-up for the study. The average age at analysis was 64 months, approximately 57 months after the dorsomedial release (range, 47–105 months). Nine out of 10 clubfeet patients did not turn up for the follow-up (clinical examination of forefoot adduction) after surgical treatment..

The complete physical examination of each foot was performed by a single clinician in a standardised and controlled manner during the patient visit. The McKay score, a validated method for clinical and functional assessment of ankle movement, muscle strength, and the presence of pain, was calculated for each patient to assess the postoperative status of surgically treated clubfoot. A score of 175 to 180 points was considered to be an excellent result; 160 to 174 equaled a good result; 125 to 159 represented an average result; 90 to 124 equaled a fair result; and scores < 90 points correlated with an unsatisfactory result (14).

We used dynamic pedobarography to evaluate the gait and posture of the clubfoot with a pressure-sensitive EMED-ST p9 platform (Novel GmbH, Munich, Germany), which records the steps with nine sensors per square centimeter at a frequency of 50 Hz. At least 3 repeated measurements were obtained for normal feet (range, 2-5) and 6 for clubfeet (range, 2-9). Moreover, a pressure-sensitive platform was used to analyse the plantar medial angle, which we renamed as the dynamic adduction angle for ease of correlating with clubfoot. This dynamic adduction angle is calculated during weight bearing by the angle created by the medial tangent of the foot and the axis of the foot (line through the center of the second toe and center of the heel) (Figure 1). All angles were calculated by the senior author with the lines captured by the pedobarograph (Figure 1). This isolated measurement of the foot is independent of the patient's foot progression angle (FPA), which may be affected by more proximal rotational deformities of the hip, thigh, knee, leg and/or ankle. In patients with clubfoot, there is adduction and varus of the foot, which brings line 'b' more medial without equivalent medialisation of line 'a', thus decreasing the angle 'c' between 'b' and 'a'. This is evident from the controls who have the mean dynamic adduction angles greater than affected clubfeet.

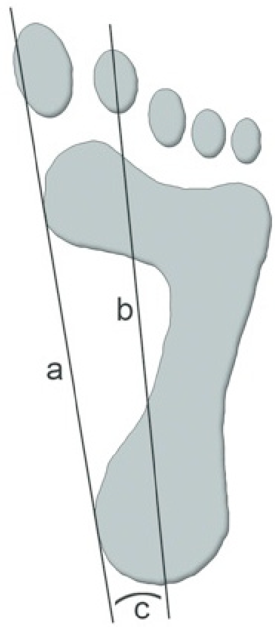

Figure 1: Experimental procedure for measuring dynamic adduction angle (a) medial tangent, (b) axis of foot, (c) dynamic foot angle.

For comparison, we performed the same dynamic pedobarography examinations in an age- and weight-matched group of 21 children without congenital foot deformities. A second control group within the study consisted of patients who had unilateral clubfoot surgically treated by a posteromedial release. We used dynamic pedobarography to compare the forefoot adduction in healthy versus surgically treated clubfoot in the second group.

Results

Twenty-three out of 33 clubfeet patients were included in the study (14 boys , 9 girls). Of them, 10 patients (6 boys and 4 girls) had bilateral clubfeet. The average patient age at follow-up was 64 months (range, 45–118 months). Mean follow-up was 75 months (range, 40–106 months). The control group included 21 children (42 feet) that required no medical assessment (13 boys, 8 girls). The mean age of the children when the dorsomedial release procedure was performed was 7 months (range, 3–14 months).

None of the children had co-morbid conditions. No complications were seen after surgery, including infection or need for repeat surgical procedures. Except for the diagnosis of clubfoot, all the children were developmentally normal.

The average dynamic adduction angle in the surgically corrected clubfeet was 4.10, whereas it was 6.4º in the unaffected feet of patients with unilateral clubfoot and 7.10 in the normal control group. Dynamic adduction angle showed a statistically significant difference using paired t test between the operated clubfeet versus the control group with normal feet, and the unaffected foot of children with unilateral clubfoot ($P < 0.001$ and $P = 0.003$, respectively) (Figure 2).

The physiologic range of the dynamic foot adduction angle (2.5° to 10.7°) was calculated using the mean of the control group (6.6°) ± 2 standard deviations. Feet with an adduction angle less than this were considered as *pes adductus*. Fourteen surgically treated clubfeet (42%) showed a persistent *pes adductus*.

In the clinical rating using the McKay score, results were excellent in 1 patient, good in 5, average in 13, and fair in 4 of the 23 patients with the operated clubfoot. All patients in the control group fulfilled criteria for excellent (65%) or good (35%) feet. We calculated the physiologic range of the foot dynamic adduction angle (2.5° to 10.7°) using the mean of the control group (6.6°) and standard deviation of ± 2. Feet with an adduction angle less than this were considered as *pes adductus*. All (34/34) feet in the control group had dynamic adduction angles > 2.5°. Fourteen (14/33 = 42%) surgically corrected clubfeet had recurrent *pes adductus* and 58% (19/33) of clubfeet had physiologic dynamic adduction angles. The mean dynamic adduction angle in the surgically corrected clubfeet was 4.9° with a range from -4.2° to 11.1°. Using a paired t test ($P > 0.05$), we found no correlation between the dynamic adduction angle and the McKay score.

Discussion

Persistent forefoot adduction is a common complication in surgically treated clubfoot. Historically, before the Ponseti technique was widely adopted, various surgical and nonsurgical options were attempted to restore anatomic alignment of the foot. Besse (15) reported that children born with a clubfoot will not have a normal foot in their adult life. Therefore, complications related to a clubfoot should be addressed to prevent unsatisfactory long-term outcomes.

Theologis et al. and Blakeslee et al. showed that nearly 41% of children in whom clubfoot had been treated had forefoot adduction, using a complex gait analysis (12,2). However, there is a paucity of literature measuring forefoot adduction using dynamic gait analysis. Our study addressed both forefoot adduction during dynamic gait analysis and the frequency of persistent *pes*

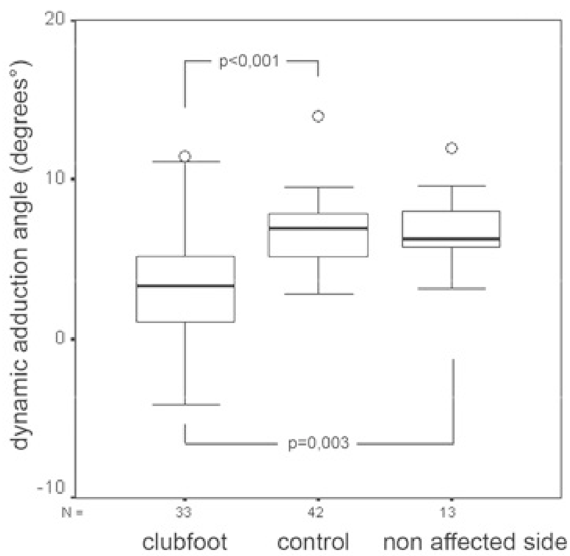

Figure 2: Dynamic adduction angle of -3.1°.

adductus after surgical treatment.

Lourenco et al. described a series of patients with moderate to severe clubfoot who underwent surgical correction (16). The most common residual deformity was forefoot adduction. Patients required a closing wedge osteotomy of the cuboid and an opening osteotomy of the medial cuneiform to correct the residual deformity once the child was older than 4 years or when the medial cuneiform ossified nucleus had developed. Use of dynamic pedobarography may aid the surgeon in predicting the need for further treatment in the clubfeet. Lee et al. concured that forefoot adduction is the most common residual deformity in the surgically treated clubfoot (17). In their study; patients underwent a posterior medial release for clubfoot and subsequently developed forefoot adduction. Thirty-five percent of patients underwent a subsequent cuboid-cuneiform osteotomy to correct forefoot adduction. Ultimately, there was a significant clinical correlation between the degrees of correction and the residual deformity. Similarly, Tarraf reviewed the cases of 125 children with 159 clubfeet who underwent reoperation for residual deformity after operative repair (18). Forefoot adduction and supination were the most common persistent deformities (95% of cases) (18). These studies indicated the importance of determining residual forefoot adduction using dynamic pedobarography after clubfoot is treated. Tarraf noted that forefoot adduction became more evident with growth, suggesting a role for dynamic gait analysis in early intervention and in determining future care as the child grows (18). In the studies by Theologis et al. (12), Lee et al. (17), and Taraff et al. (18), all the forefoot adduction was measured in a static fashion. In our study, we used the same pedobarograph method as described by Hughes et al, which reported good reliability for the EMED-F system, with two sensors per square centimeter and a setting of 20 Hz (19). While it has good reliability, the angle created (in essence between the medial border of the foot and the 2nd ray axis) may under-represent the true deformity, as adduction of the 2nd ray also occurs with forefoot adduction in addition to supination. As previously studied by Lee et al. and Tarraf et al. patients who underwent a posterior medial release may develop forefoot adduction in approximately 42% of the cases (17,18).

Several studies have commented on the clinical outcome of patients who developed forefoot adduction; however the data shows that further investigation is needed. In a multicenter study by Saetersdal et al., the clinical outcomes of adduction deformities were compared between types of bracing treatment (20). They found no significant difference between the clinical outcome in patients that developed forefoot adduction status-post Ponseti method and the method of bracing used (bilateral foot abduction brace vs unilateral above-the-knee brace) (20). Moreover, Elgeidi and Abulsaad, published a study in which patients with forefoot adduction and midfoot supination were corrected surgically by combined double tarsal wedge osteotomy.22 The authors noted clinical satisfaction in every patient, no deterioration of the correction at the 5-year follow-up, and minimal complications (21). These studies demonstrate that more investigation are needed for correlating the development of forefoot adduction and clinical outcomes.

In this study, clinical evaluation using the McKay score showed good or excellent results in only every fourth patient 25% (14). In the clinical studies performed by Reichel et al., Lau et al., and Imhäuser et al. the excellent or good outcome was higher (80%, 66.6%, and 70% respectively) compared to our results (3,4,22). In these studies the post-surgical results were reported from the departments with more than average experience, e.g., 3000 treated clubfeet (22). In the present study, the surgical experience was around 300 at the time of the study. No studies to date have described the learning curve associated with the treatment of clubfeet. We found no statistical correlation between the dynamic adduction angle and the McKay score. Currently there are no studies in literature to our knowledge that show a relationship between dynamic adduction angle and poor functional outcomes, leading the dynamic adduction angle to be possibly cosmetic.

This study has several limitations. It was retrospective and thus not randomised or blinded and possibly subject to recall bias. Although the treatment technique was performed in the same manner on all subjects by single clinician, the technique has not been clinically validated. Finally, the McKay score is partially subjective clinical rating which in our study was assigned by the clinician during the follow-up visits.

Although we reviewed the clinical results of patients undergoing a posteromedial release rather than patients treated with the Ponseti method (the current trend), the forefoot adduction is important irrespective of the methods of correction used for clubfoot. A large multicenter study addressing outcome measures of forefoot adduction in clubfeet treated with the Ponseti technique, and studying the timing for repeat surgery if necessary, would be interesting.

Till date research has foccused on forefoot adduction as a common residual deformity in surgically treated clubfoot; however, studies in the future should likely focus on methods to determine forefoot adduction in non-surgically treated clubfeet. Even though, the measurement does not encompass everything, it does describe a novel technique to collect additional clinical data in the assessment of forefoot adduction by using dynamic gait analysis. Early identification of persistent *pes adductus*, irrespective of the initial treatment (surgical or non-surgical), may allow early conservative treatment to help avoid surgical intervention.

Conclusion

Although we observed a high occurrence of dynamic adduction angle as measured by dynamic pedobarography in surgically treated clubfeet, there was no correlation between forefoot adduction, dynamic forefoot adduction angle, and clinical outcome measures. Further investigation is needed into the relevance of increased forefoot adduction angles as measured by dynamic pedobarography as it pertains to clinical management of surgically treated clubfeet.

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Conflict of Interest

None.

Authors' Contributions

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Drafting of the article: NHA, AV, MJM
Critical revision of the article for important intellectual content: NHA, AJ, AV, MJM
Final approval of the article: NHA, AJ
Provision of study materials or patients: NHA, AJ, MJM
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