Journal of Manipulative and Physiological Therapeutics
Volume 22 • Number 4 • May 1999
0161-4754/99/$8.00 + 0 **76/1/97664** © 1999 JMPT

Radiographic Evaluation of Weight-bearing Orthotics and Their Effect on Flexible Pes Planus

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ABSTRACT

Objective: To determine whether any positive change in the alignment of the bones of the feet occur with the use of custom-made flexible orthotics, cast by weight bearing, in individuals having flexible pes planus.

Methods: Anteroposterior and lateral radiographs were obtained with and without orthotics in place. The anteroposterior and lateral talocalcaneal angles and the lateral pitch of both the left and right foot were assessed.

Results: The *t* test values and *P* values derived from the radiographic measurements indicated statistically significant improvements in weight-bearing foot alignment.

Discussion: Biomechanical faults in the pedal foundation can adversely affect any of the joints and structures of the foot/ankle complex, lower extremities, pelvis, and spine.

Conclusion: This study supports the use of a custom-made flexible orthotic for the improvement of pedal structural alignment. (J Manipulative Physiol Ther 1999;22:221-6)

Key Indexing Terms: Orthotics; Weight-bearing; Radiography; Kinetic

INTRODUCTION

The purpose of this study was to determine whether any positive structural changes in the alignment in the bones of the feet occurred with the use of custom-made flexible orthotics in individuals with flexible pes planus. The feet, which contain one-quarter of the body's bones, are vulnerable to structural deficits such as plastic deformation of the connective tissues and malalignment of bones, leading to excessive pronation or supination.[1,2]

The foot demonstrates three arches that, when properly aligned, give exceptional supportive strength (Fig 1). The medial longitudinal arch (*A* to *C*) extends from the calcaneus through the first three metatarsals. It is the longest and highest arch and is the most important during static support, movement, and shock absorption. The keystone of the medial arch is the navicular bone. The lateral arch (*B* to *C*) extends from the calcaneus through the last 2 metatarsals. It is shorter and lower than the medial arch. Its keystone is the cuboid. Subluxation of the cuboid is a common cause of lateral foot pain. The metatarsal or anterior transverse arch (*A* to *B*) is the hollow in the inner part of the sole just proximal to the metatarsal heads. Precise placement of metatarsal pads under this arch is one of the most effective treatments for metatarsalgia, the most common pain syndrome of the forefoot.[3]

"Pes planus" refers to any condition of the foot in which the medial longitudinal arch is lower than established normal parameters.[4] The term is commonly modified by adjectives such as "flexible," "rigid," "congenital," or "acquired." This study limited its scope to flexible pes planus. A foot with an observable medial arch while in a non-weight-bearing position (sitting or recumbent) and the absence of this arch while in a weight-bearing position (standing) is classified as "*flexible* pes planus."[5] The reduction of the medial longitudinal arch results from plantar deviation (inward or medial rotation) of any of its three articulations: the talocalcaneal joint, the talonavicular joint, and the naviculocuneiform joint.[6]

Numerous studies have documented the relationship between pes planus and biomechanical and kinesiologic aberrations such as plantar fasciitis, calcaneal spurs, patellar tracking problems, pelvic unleveling, alteration of marrow signal on magnetic resonance imaging, and myofascial low back pain.[7-15]

Orthotic devices are hypothesized to support the foot/ankle complex in a more near-normal structural alignment while in the weight-bearing position. However, few studies have been performed to demonstrate changes in structural alignment produced by orthotics on pes planus. Mereday et

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Paper submitted May 22, 1998; in revised form July 9, 1998.

Orthotics used in this work were donated by Foot Levelers, Inc., Roanoke, Virginia.

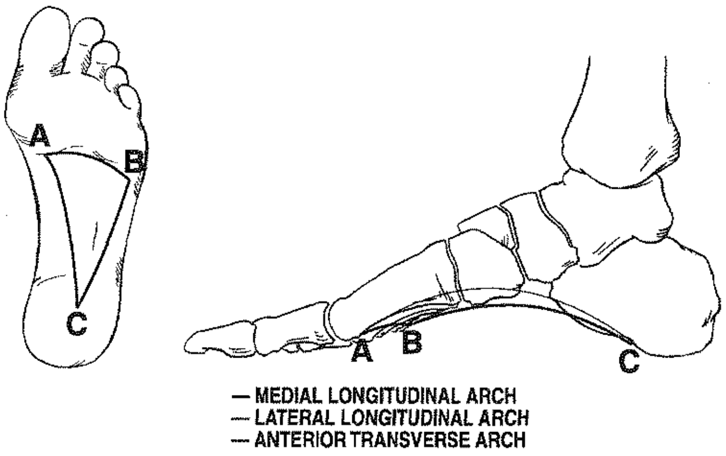

Fig 1. *Arches of the foot.*

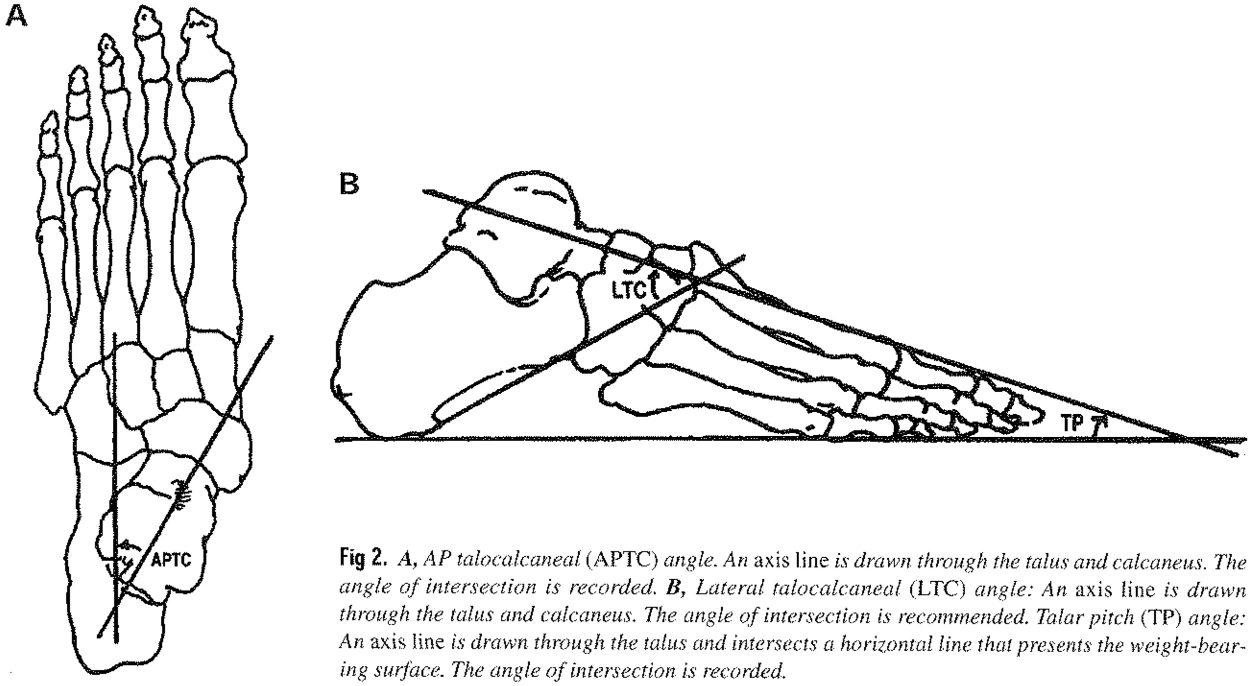

Fig 2. *A, AP talocalcaneal* (APTC) *angle. An* axis line *is drawn through the talus and calcaneus. The angle of intersection is recorded.* ***B,*** *Lateral talocalcaneal* (LTC) *angle: An* axis line *is drawn through the talus and calcaneus. The angle of intersection is recommended. Talar pitch* (TP) *angle: An* axis line *is drawn through the talus and intersects a horizontal line that presents the weight-bearing surface. The angle of intersection is recorded.*

al,[8] Riegler,[16] and Bates et al[17] evaluated rigid or semirigid orthoses. Our literature review failed to uncover any studies demonstrating structural changes produced by the use of custom-made flexible orthotics.

This study compares lines of mensuration on radiographs of the foot/ankle complex in a weight-bearing position without and with a custom-made flexible orthotic to determine whether this particular type of orthotic provides structural support.

MATERIAL AND METHODS

This study focused on the radiographic measurements of the lateral talar pitch, the anteroposterior (AP) talocalcaneal angle, and the lateral talocalcaneal angle; those are altered by medial deviation of the talus.[7] The criteria used was derived from methods used in studies performed by Mereday et al[8] and Kalen and Brecher.[9]

Mereday et al[8] and Kalen and Brecher[9] used radiographs of the foot in a weight-bearing position with and without orthotics. Mereday et al[8] examined the talocalcaneal angle and the talus—first metatarsal angle on AP and lateral projections. Kalen and Brecher[9] also measured the talocalcaneal angle on AP and lateral radiographs. Additionally, the calcaneal plantar angle and the talar pitch were measured on the lateral projections, and the talonavicular angle was measured on the AP projections.

On the basis of their experience, our study examined the following three angles: AP talocalcaneal (Fig 2, *A*), lateral

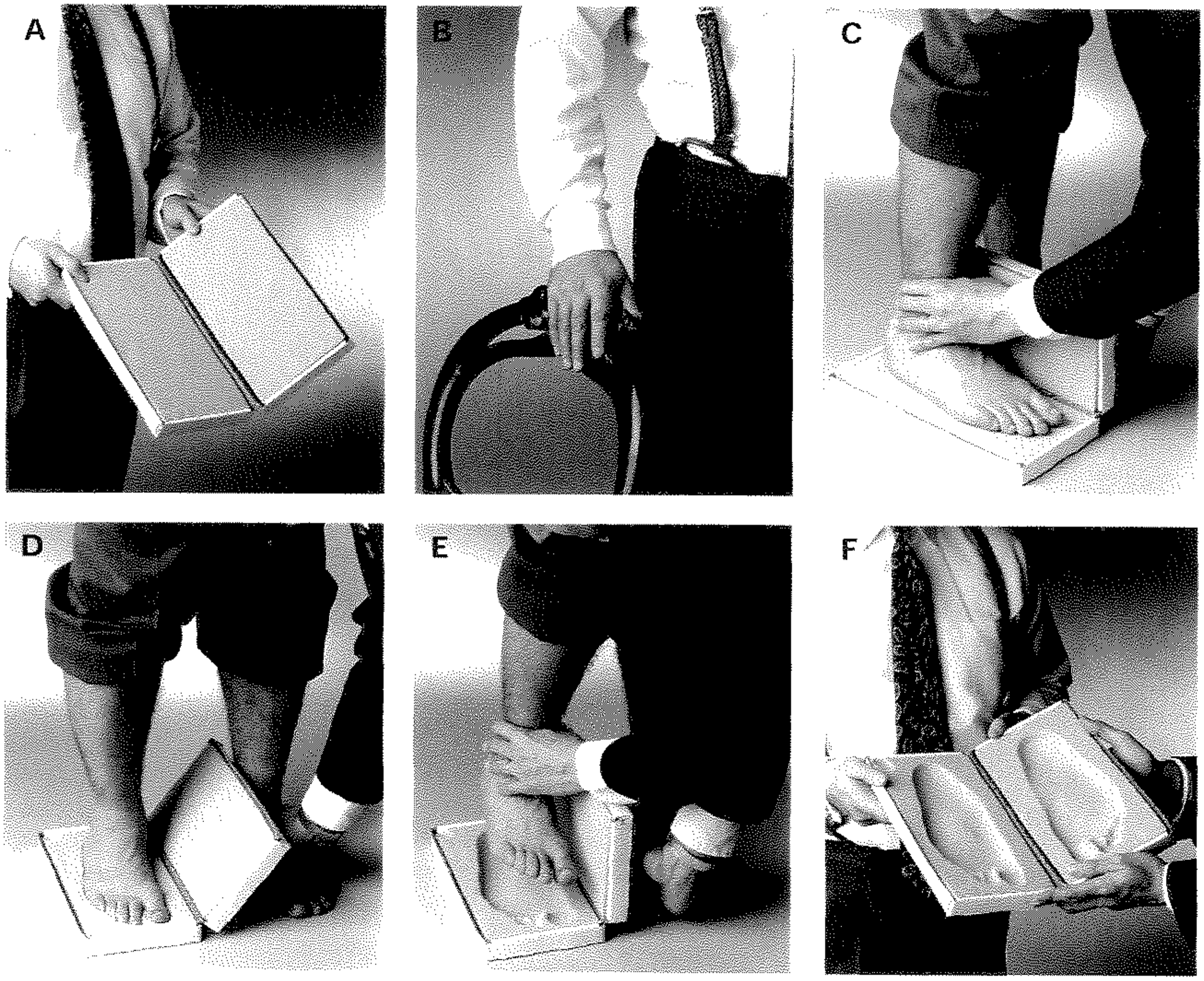

Fig 3. *Weight-bearing casting procedure.* ***A,*** *Step 1. Show the casting kit to the patient and briefly describe the procedure.* ***B,*** *Step 2. The patient stands in a normal posture with 1 hand holding onto a stable object (such as a chair, desk, or wall).* ***C,*** *Step 3. As the patient looks straight ahead and lifts up one foot, gently guide the foot onto the casting kit.* ***D,*** *Step 4. The patient steps into the casting kit, pressing the foot to the bottom of the box. Gently push the patient's toes down and extend his/her knee to ensure full weight bearing of the heel.* ***E,*** *Step 5. After the patient lifts the foot straight up, remove the casting kit.* ***F,*** *Repeat steps 2 through 5 for the other foot.*

talocalcaneal (Fig 2, *B*), and talar pitch (Fig 2, *B*). Great care was taken to mark the bony landmarks consistently.

Twenty-two subjects, ages 6 to 57 years, were selected from patients in the Montgomery Health Center at Logan College of Chiropractic. Selection criteria included the following: ambulatory individuals, observable medial longitudinal arch when in a non-weight-bearing position, and obvious reduction or absence of the medial longitudinal arch when in a weight-bearing (standing) position. For each subject a cast was produced with the patient in a weight-bearing position (Fig 3), following the standard protocol, from which a pair of custom-made Full Length FirmFlex Plus flexible orthotics was manufactured by Foot Levelers, Inc, Roanoke, Va.

To assess the effects of these particular orthotics on bony alignment, 2 sets of 2 radiographs of each foot were obtained. Each set of radiographs consisted of an AP and lateral view taken with the subjects wearing their shoes. The first set was taken without the orthotics, and the second set was taken with the orthotics in place. The radiographic studies were performed with a Bennet 100 kHz high-frequency X-ray machine, and images were obtained with Kodak cassettes and film. Subject exposure was minimized by proper collimation, lead apron shield, and the use of aluminum filters when appropriate.

For the AP view, the X-ray tube was tilted 15 degrees cephalad from vertical, at a distance of 40 inches. The cassettes were placed on a level floor. The subject stood on a

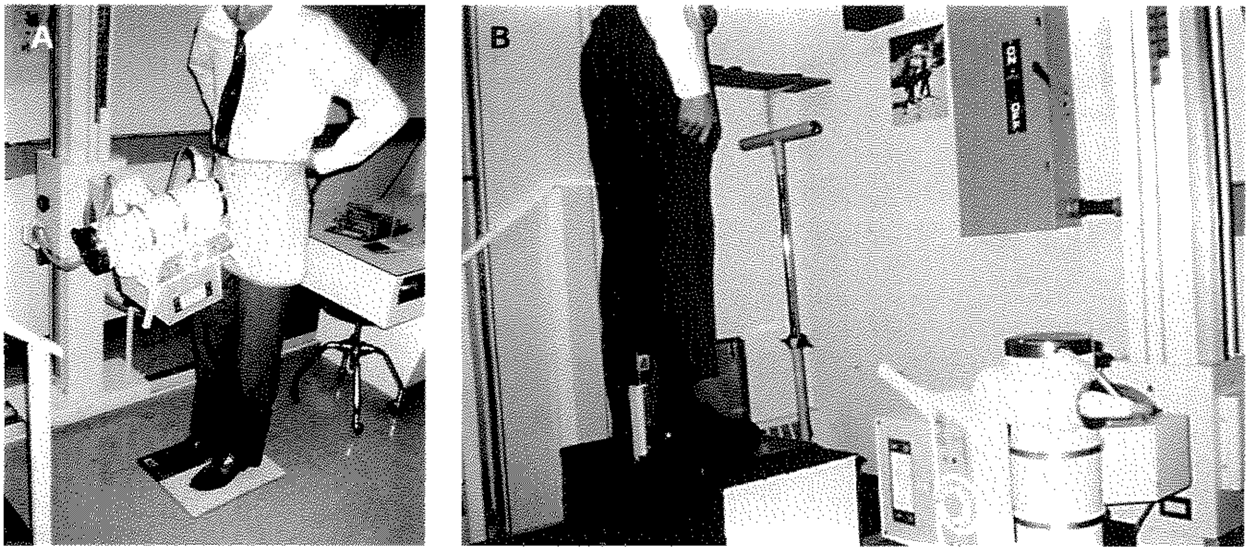

Fig 4. *A, Patient is positioned for the AP view of the foot in weight bearing. **B,** Patient is positioned for the lateral view of the foot in a weight-bearing position.*

Table 1. *Paired samples statistics*

		Mean	N	SD	SEM
Lateral talocalcaneal					
Pair 1	R insert	42.8636	22	5.1943	1.1074
	R without	44.6818	22	5.5497	1.1832
Pair 2	L insert	43.6364	22	4.7664	1.0162
	L without	46.8182	22	5.5174	1.1763
Lateral talar pitch					
Pair 1	R insert	22.5455	22	3.0819	.6571
	R without	24.6818	22	3.7971	.8095
Pair 2	L insert	23.3182	22	4.2132	.8983
	L without	27.0455	22	4.8154	1.0267
AP talocalcaneal					
Pair 1	R insert	19.4091	22	4.8566	1.0354
	R without	22.9091	22	4.6179	.9845
Pair 2	L insert	18.9091	22	4.8492	1.0339
	L without	22.5909	22	5.0300	1.0724

R insert, Right with insert; *R without,* right without insert; *L insert,* left with insert; *L without,* left without insert.

Values are increased with decreased arch height.

Table 2. *Paired samples correlations*

		N	Correlation	Significance
Lateral talocalcaneal				
Pair 1	R insert and R without	22	.899	.000
Pair 2	L insert and L without	22	.845	.000
Lateral talar pitch				
Pair 1	R insert and R without	22	.679	.001
Pair 2	L insert and L without	22	.741	.000
AP talocalcaneal				
Pair 1	R insert and R without	22	.781	.000
Pair 2	L insert and L without	22	.719	.000

R insert, Right with insert; *R without,* right without insert; *L insert,* left with insert; *L without,* left without insert.

Values are increased with decreased arch height.

pair of cassettes with body weight distributed equally on each foot (Fig 4, *A*). The central ray was directed toward the talocalcaneal joint with the cathode toward this joint to maximize the anode heel effect. Twenty points of Nolan aluminum filters were added to prevent overexposure of the metatarsals and phalanges. The technique was manually set at 80 KVP, 25 MA, and 1.9 to 2.5 MAS. Metallic objects were placed at the posterior borders of the talus and calcaneus to enhance visualization. Reference lines were drawn by the principal examiner through the longitudinal axis of the head and neck of the talus and calcaneus.

The lateral views required the subjects to stand on the 2-step 24-inch platform and the cassette to be positioned perpendicular to the central ray (Fig 4, *B*). The X-ray tube position was 90 degrees from vertical and at a distance of 40 inches with the central ray directed toward the cuboid. The technique settings were 60 KVP, 75 MA, and 1.9 MAS. The radiographic reference lines were drawn by the principal examiner through the longitudinal axis of the talus, the calcaneus, and the plane of weight support.

Measurements were made by the principal examiner using a goniometer. Computerized analysis of the related angles from each set of radiograms was performed on Microsoft Excel. Statistical changes were observed by use of standard *t* testing.

RESULTS

All of the three angles studied demonstrated changes that were statistically significant. Tables 1, 2, 3, and 4 contain the recorded measurements for the angles examined. The patients were radiographed while in a weight-bearing position, both with and without the orthotics in place.

The AP talocalcaneal angle will increase in patients with pes planus. Evidence of arch support and improved structur-

Table 3. *Paired samples test*

		Paired differences					
					95% CI of difference		
		Mean	SD	SEM	Lower	Upper	t
Lateral talocalcaneal							
Pair 1	R insert and R without	–1.8182	2.4424	.5207	–2.9011	–.7353	–3.492
Pair 2	L insert and L without	–3.1818	2.9542	.6298	–4.4916	–1.8720	–5.052
Lateral talar pitch							
Pair 1	R insert and R without	–2.1364	2.8334	.6041	–3.3926	–.8801	–3.537
Pair 2	L insert and L without	–3.7273	3.2976	.7031	–5.1894	–2.2652	–5.301
AP talocalcaneal							
Pair 1	R insert and R without	–3.5000	3.1434	.6702	–4.8937	–2.1063	–5.223
Pair 2	L insert and L without	–3.6818	3.7082	.7906	–5.3260	–2.0377	–4.657

R insert, Right with insert; *R without,* right without insert; *L insert,* left with insert; *L without,* left without insert.
Values are increased with decreased arch height.

al alignment would be demonstrated by a decrease in this measured angle. Thirty-five of 44 angles demonstrated improvement. Six of the 44 demonstrated no change.

The lateral talocalcaneal angle will increase in patients with pes planus. Evidence of arch support and improved structural alignment would be demonstrated by a decrease in this measured angle. Thirty of the 44 angles demonstrated improvement. Six of the 44 demonstrated no change.

The lateral talar pitch angle increases in patients with pes planus. Evidence of arch support and improved structural alignment would be demonstrated by a decrease in this measured angle. Thirty-three of the 44 angles demonstrated improvement. Four of the 44 demonstrated no change.

Overall, the AP talocalcaneal angle improved by an average of 15%. The lateral talocalcaneal angle improved by an average of 5%, and the lateral talar pitch angle improved by an average of 11%. The *t* test values ranged from 3.49 to 5.3 with a critical value of 2.08. *P* values were well below .05 (Tables 1, 2, and 3).

DISCUSSION

Structural malalignment is a source of biomechanical stress to the bones, muscles, ligaments, and nerves. A closed kinetic chain is formed throughout the lower extremity and pelvis during standing, walking, or running. Altered joint alignments will result in abnormal tension, torque, and compressive forces. The feet play a critical role in this kinetic chain by providing support, mobility, and shock absorption. When structural faults are present in the pedal foundation, consequences such as first metatarsophalangeal dysfunction, Achilles tendon stress, Q-angle alterations at the knee, functional leg length inequality, and an unlevel pelvis with attending scoliosis may also be present.[10,11,18]

During the gait cycle, individuals with pes planus have prolonged excessive pronation (inward or medial rotation) of the medial arch during the midstance and propulsion phases resulting in multiple cumulative trauma to the foot/ankle complex, knees, hips, and low back.[12] A recent study by Schweitzer and White[19] demonstrated on magnetic resonance imaging that bone marrow edema could be induced by creating a biomechanical fault in the pedal foundation.

Table 4. *Paired samples test*

		df	Significance (2-tailed)
Lateral talocalcaneal			
Pair 1	R insert and R without	21	.002
Pair 2	L insert and L without	21	.000
Lateral talar pitch			
Pair 1	R insert and R without	21	.002
Pair 2	L insert and L without	21	.000
AP talocalcaneal			
Pair 1	R insert and R without	21	.000
Pair 2	L insert and L without	21	.000

R insert, Right with insert; *R without,* right without insert; *L insert,* left with insert; *L without,* left without insert.
Values are increased with decreased arch height.

Several researchers have found correlations between impaired proprioceptive feedback and pes planus. Improper joint orientation results in decreased proprioception, contributing to a greater dependency on visual input for postural stability.[20] The cross-crawl patterning of arm and leg swing is adversely affected.[13] Increased mechanoreceptor firing of muscles, tendons, and ligaments not only affects dynamic equilibrium but may also contribute to visceral dysfunction.[21] Otman et al[14] found that walking heart rate, oxygen consumption, systolic blood pressure, and energy cost values were improved when individuals with flat feet were biomechanically improved with orthotics.

One clinical hypothesis is that orthotic devices are used to align and support the foot/ankle complex in a more near-normal physiological position for a weight-bearing foot, to prevent dysfunction, or improve function of movable body parts.[15] Therefore orthotics should be designed to do the following:

- Create a symmetrical foundation by blocking pronation or supporting supination—an asymmetric pedal foundation is a contributing factor in pelvic unleveling, flexible scoliosis, and low back pain.[22-25]
- Provide heel strike shock absorption—the natural shock absorption capacity of the foot/ankle complex is reduced with either pronation or supination. Pronated feet are more susceptible to metatarsal stress fractures, whereas

the calcaneus and tibia are more susceptible to stress fractures with supination.[17,26]

- Inhibit serial biomechanical stress applied to the kinetic chain—the inward rotation of the foot/ankle complex, tibia, and fibula are contributing factors in patients who exhibit frequent ankle sprains, lower leg compartment syndromes, patellofemoral dysfunction, medial knee degenerative joint disease, stress fractures, iliotibial band inflammation, pelvic unleveling, and low back pain.[25,27,28]
- Enhance neuromuscular re-education—the sensory information from the mechanoreceptors of the foot are altered in cases of pes planus, adversely affecting balance, gait, reciprocal inhibition, innervation of muscles, and posture.[29-31]

CONCLUSION

This study demonstrated that use of orthotics had a normalizing influence on the investigated angles of assessment. The improvement of the pedal structural alignment by use of these particular custom-made flexible orthotics (Full Length FirmFlex Plus) manufactured by Foot Levelers, Inc. was statistically significant. It is recommended that further study into the potential clinical effects of improved pedal biomechanics be pursued. These areas may include pain reduction and improved dynamic function.

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