CLINICAL ASSESSMENT OF MOLDED FOOT ORTHOTICS USING FRONTAL PLANE GROUND REACTION FORCES

BAUER, T.; FACEY-CROWTHER, L.A.; ALA KORPI, T.
Lakehead University
Intercity Orthopaedics
Ontario
Canada

INTRODUCTION

Foot orthotic appliances are currently being utilised by practitioners to correct foot deformities and malalignment problems in the lower extremity. Recent developments in materials design, diagnostic procedures and biomechanical assessment have provided more effective appliances plus a more comprehensive assessment of their effectiveness (5,6,12,2,18,3,19).

The foot orthotic system used in this study is the Orthofoot 2000 system which is an in house fabrication process designed for application in the clinical setting (14,1). The primary advantages of the system are speed of fabrication, individualized and accurate molding of the device to the shape of the patient's foot. Postings and additional protective and structural additions can be affixed to the orthotic based on the prescription. The appliance also provides comfort and shock absorbency according to the density of the materials selected.

This study presents a description of the diagnostic procedure, the orthotic construction and ground reaction force testing to verify the effectiveness of the clinical treatment.

PRONATION MALFUNCTION IN THE FOOT

The function of the orthotic prescription in this study was directed toward patients who experienced abnormal foot mechanics specifically, pronation. Normal pronation during foot strike is a complex combination of dorsiflexion, abduction and eversion (9). The talo crural joint complex plus the subtalar, transverse tarsal and forefoot articulations combine together to allow for normal force transfer during heel strike to toe off (1,4). Abnormal mechanics can result in prolonged calcaneal eversion beyond approximately 25% of the stance phase (16). Normal calcaneal eversion at foot strike combines with knee flexion to absorb initial impact forces. Extended eversion results in an unstable forefoot during mid stance and push off phases, when a rigid foot lever is required. Parallel subtalar and mid tarsal joint alignment during foot strike provides instability for eversion. However, if this instability is not corrected through inversion during the mid stance phase, forefoot instability results. A loss of forefoot stability for plantarflexion of the first ray during push off is also a result of extended and excessive pronation (7).

The failure of the foot to correct from calcaneal inversion can be result of varus which can severely inhibit forefoot mechanics during the mid stance and toe off phases (15). A forefoot varus deformity is a mid tarsal joint abnormality resulting from a failure of the head and neck of the talus to derotate from the original infantile position. A compensated forefoot varus presents as a pes planus with the calcaneus everted posteriorly. Depending on the degree of compensation, the medial longitudinal arch is collapsed and plantar surface deformities such as a hallux valgus may develop. Uncompensated, forefoot varus may result due to a lack of subtalar pronation. In this instance a development of a callus under the fourth and fifth metatarsal heads often results (9).

ORTHOTIC FUNCTION

The function of the foot orthotic is to bring the contact surface to the foot in order to avoid excessive deviation from the subtalar neutral position (9). Rearfoot eversion is controlled using a medial heel wedge (17) and forefoot varus is corrected using a medial posting (17). The degree of posting has been outlined by Donatelli (5). Based on patient test data, mean averages, indicated forefoot varus postings of 5.2^{0} and 4.5^{0} for rearfoot varus postings in 90% of the patient population. Procedures for posting the orthotic in this study were slighty changed based on clinical experience and used approximately 60% of the measured malalignment.

DIAGNOSTIC PROCEDURE

The diagnostic procedure included static weight bearing and non weight bearing measures. Vertical lines through the midline of the calcaneus and calf were marked and subtalar inversion eversion measured using manual force and a flexible plastic goniometer (Fig.1). In the same position forefoot to rearfoot alignment were measured after placing the foot in subtalar neutral (Fig.2). Measures were repeated three times plus repeated by a second tester to improve reliability of the measures. Tibial and femoral torsion were also measured in a non weight bearing position. Forefoot, mid foot and hind foot flexibility were manually tested to determine any noticeable lack of range in the mid and forefoot articulations.

Hindfoot subtalar and talo crural joint flexibility were measured in a non weight bearing position using a goniometer (Fig. 3).

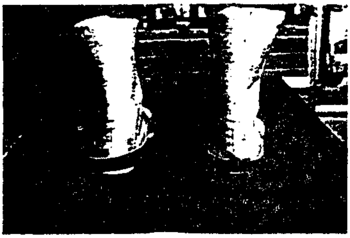

Figure 1: Rearfoot markings for diagnostic measures.

Figure 2: Forefoot to rearfoot alignment.

A qualitative dynamic analyses was performed while walking. Gait angle, including toe in and toe out was observed for degree of ab and adduction during each of the gait phases. The foot positions were observed during heel strike, midstance and push off to detect compensatory adjustments related to lower extremity malalignments.

Based on the diagnostic results, specific therapy and orthoses were prescribed. Individualized orthotic prescriptions were in some instances combined with the use of antipronation running or walking shoes.

Figure 3: Hindfoot subtalar and talocrural joint flexibility measures.

Figure 4: Molded orthotic construction.

ORTHOTIC CONSTRUCTION

Orthotic materials were selected according to the patients' specific symptomology, activity level and comfort (15). The Orthofoot 2000 molded Orthotic system uses a shell which conforms to the patients' heel contour and foot size. The foot is placed into the shell while the patient is in a seated position and the ankle is manipulated into sub talar neutral (ST). (Fig. 4). This position is achieved through palpation of the talus while manipulating the foot to find the neutral talar position. Extremes in supination and pronation are adjusted to position the foot into neutral and the position is maintained during the molding of the orthotic. Polyurethane foam resins are mixed and poured into the shell, which is then covered by a permanent orthotic top cover. The foot is placed on the top cover and held against a heel guide to ensure a correct heel cup formation. The polyurethane foam sets to the contours of the foot as downward body weight pressure is applied. A knee strap is used to maintain the vertical force and to minimize excessive thickness of the orthotic. The foam cures within a few minutes and can be removed, trimmed and cut to fit the shoe. Edges are ground and sanded smooth to prevent friction blisters. Based on the initial diagnostic procedure posting is completed using wedges applied to the interior surface of the orthotic to accommodate for malalignment in the forefoot or rearfoot. Specific shoes are also specified to assist in support and correction.

ORHOTIC POSTING

The procedures for posting the orthotic are based on Donatelli (5) and involve rear and forefoot varus posting. Posting wedges are selected according to the diagnostic measures. In the neutral standing position the great toe is non weight bearing. The orthotic prescription is designed to raise the contact surface to the foot through a medial forefoot posting to prevent excessive compensatory calcaneal eversion. Adhesive wedges of varying degrees are attached to the appropriate area of the orthotic (Fig. 5.) Based on the rear to forefoot measures a forefoot varus is posted 50-60% up to a maximum of 8^{0} of the measured malalignment. A forefoot valgus is posted 60% to a maximum of 4^{0} of the measured hind foot malalignment. Generally the rearfoot is posted 1^{0} less than the forefoot depending on the available rear foot motion or subtalar mobility. A heel lift may be included to control a possible restricted equinas plus relief areas may be built into the orthotic to control pressure areas such as corns and heel spurs.

Figure 5: Rear and forefoot orthotic wedge postings.

TEST METHODOLOGY

Patients were referred from general practitioners and orthopaedic surgeons to the foot clinic for various lower limb foot and pain syndromes including plantar fascitis, shin splints, halux valgus, metatarsalgia and patella femoral syndrome. The patients specifically selected for the study were typical forefoot varus pronators. Patients were tested on a force plate one month post orthotic construction at the Lakehead University Biomechanics laboratory. Orthotics construction was based on a prescription developed through a clinical diagnostic procedure adapted from procedures developed by Donatelli, 1985. The diagnosis was also based on patient history, activity level, profession, dress requirements and specific foot abnormalities. The patients tested were chosen as typical pronators with forefoot varus symptomology.

FORCE PLATE ANALYSIS

Following the diagnoses, construction and fitting of the orthotics patients were reassessed using both static and dynamic gait measures. The orthotics and posting wedges were rechecked and adjusted to ensure correct fit (Fig. 1). Patients were booked for a force plate analysis approximately one month post fitting. This period was considered sufficient time to adjust to the orthotic and footwear if prescribed. Patients were directed to use the shoes which were normally used with the orthotic. Testing was completed without footwear, footwear only and footwear combined with the orthotics. The patient was instructed to practice walking over the force plate until they were able to strike the plate repeatedly with a relaxed and natural gait stride. A minimum of 15 trials were repeated for both feet. Trials where the stride was not natural or where the stride length was extended or shortened were cancelled. The patient was instructed to provide additional feedback concerning abnormal trials.

The hardware system included the A.M.T.I. force plate with gait analysis and statistical analysis software. Pilot studies indicated extreme variance in ground reaction force data when low trial numbers were used. As a result 15 trials were taken for each of the test conditions, barefoot, shoes, and shoes with orthotics. Frontal (x) plane Ground Reaction Forces (GRF) was used to measure the variation in medial (pronation) forces under the foot. Time to maximum pronation (TMP), maximum force to pronation (MFP) and mean force over 30% stance time (F-30% ST) were the measurement variables. The orthotic construction is designed to prevent excessive deviation of the foot from the sub talar neutral position. The GRF measures used are considered strong indicators of excessive or prolonged calcaneal eversion. The effects of the orthotic and shoes are measured against the barefoot trials.

The effectiveness of the orthotic shoe combination in controlling extended compensatory pronation is concluded through the frontal (x) plane GRF measures.

RESULTS

Results for left and right foot force plate measures are presented in Table 1. Mean values from 15 trials including TMP, MPF and F-30% ST are listed for each condition; barefoot, orthotic and shoes. For statistical analysis the data is ordered for a sign test analysis. Positive (+), Negative (-) or (0) signs indicate a decrease (+), increase (-) or no change (0) between the barefoot test and the orthotic and shoe test condition.

TABLE 1
Force Plate Results
Frontal (X) Plane Ground Reaction Forces

A - TMP. - Time to Pronation (Secs), B - MPF. - Maximum Pronation Force (Newtons), C - F 30% S.T. - Mean Force over 30% Stance Time.
$\bar{X}$ - 15 Trials.

SUBJECT	ORTHOTIC	CHANGE	BAREFOOT	CHANGE	SHOE	VARIABLE
1-L	.61	+	.64	0	.64	TMP-A
	62.7	+	72.5	+	70.2	MPF-B
	19.3	+	19.8	-	16.7	F30%-C
1-R	.21	+	.23	+	.18	A
	43.4	-	38.9	-	40.7	B
	13.8	+	17.9	+	15.26	C
2-L	.32	+	.34	+	.24	A
	34.3	+	42.5	-	44.2	B
	7.2	+	15.5	+	12.06	C
2-R	.19	+	.32	+	.24	A
	27.8	+	30.6	-	34.5	B
	2.18	+	10.6	+	6.36	C
3-L	.24	+	.51	+	.31	A
	62.31	+	98.2	+	75.9	B
	21.3	+	44.1	+	28.4	C
3-R	.39	+	.53	+	.43	A
	63.2	+	91.3	+	71.1	B
	21.3	+	29.9	+	28.4	C
4-L	.11	+	.16	0	—	A
	11.0	+	14.2	0	—	B
	2.7	+	3.1	0	—	C
4-R	.25	+	.35	0	—	A
	23.5	+	27.6	0	—	B
	4.51	+	6.94	0	—	C
5-R	.14	+	.3	+	.25	A
	64.1	+	70.8	+	65.4	B
	15.79	+	33.8	+	15.05	C
6-R	.56	-	.44	-	.45	A
	92.4	-	87.1	+	85.8	B
	56.8	-	47.1	+	44.2	C
6-L	.14	+	.23	+	.19	A
	30.2	+	32.4	-	34.9	B
	3.17	-	2.8	-	4.75	C
7-R	.3	-	.14	-	.25	A
	65.4	+	70.4	+	64.1	B
	15.79	+	33.8	+	15.35	C
8-L	.02	+	.05	0	.05	A
	47.0	+	55.8	+	53.1	B
	2.8	+	3.0	+	1.85	C

STATISTICAL ANALYSIS

Sign tests for ordered data were performed to indicate significance between the independent variables, barefoot to orthotic and barefoot to shoe. Changes in TMP, MPF and F at 30% ST from barefoot to orthotic and barefoot to shoe were indicated as positive (+) or negative (-) (13).

Results indicated significant changes (0.05) in TMP, MPF and F at 30% ST between barefoot readings and orthotic readings (Table 1 and 2). The indication is that TMP, MPF and F - 30% ST all indicated decreases using the orthotic. These results demonstrate that the molded orthotic significantly reduced calcaneal inversion time (TMP) plus reduced the magnitude of the inversion forces (MPF) applied medially under the foot in most patients. The average force over the first 30% of stance time was also significant and is an indication that the magnitude of forces during the initial stages of foot strike is reduced (F - 30% ST). As calcaneal eversion occurs during the initial stages of heel strike this result indicates that the orthotic is effectively controlling the motion.

The sign test for significance between barefoot and prescribed footwear indicated no significance between any of the variables TMP, MPF and F - 30% ST. This result indicates that the prescribed footwear did not effectively control the time to pronation or the medial forces acting to control calcaneal eversion. As all patients were not wearing identical footwear and the footwear was at different stages of wear these results are not unexpected. Further testing is required to verify the effectiveness of specific brand name anti pronation shoes which demonstrated some degree of success in a number of patients.

TABLE 2
Test of Significance (0.5) Using Ordered Sign Test

		ORTHOTIC			SHOE		
		TMP	MPF	F-30%ST	TMP	MPF	F-30%ST
BAREFOOT	TMP	*			-		
	MPF		*			-	
	F-30%ST			*			-

TMP - time to maximum pronation
MPF - maximum pronation force
F-30%ST - mean force over 1st 30% stance time
* - significance at .05 level

CONCLUSION

The use of the prescription molded orthotics for foot pronation used in the study demonstrated a significant level of success based on frontal plane (x) FRF plate measures. These results agree with the high rate of pain symptom reduction reported by patients and verify the function of the orthotic in controlling forces under the foot and limiting excessive pronation from the sub talar neutral position.

REFERENCES

1. ADELAAR, R. S.: The Practical Biomechanics of Running. The American Journal of Sports Medicine, Vol. 14, No. 6, 1986.
2. BATES, B. T., L. R. OSTERNIG, B. MASON, L. S. JAMES: Foot Orthotic Devices to Modify Selected Aspects of Lower Extremity Mechanics.
3. BATES, B. T.: Evaluation of Foot Orthotic Appliances Using Ground Reaction Force Data. Proceedings, Canadian Biomechanics Society Conference, Kingston, Ontario 1984.
4. DONATELLI, R.: Normal Biomechanics of the Foot and Ankle. Journal of Orthopaedic and Sports Physical Therapy

1985, p. 91-95.
5. DONATELLI, R.: Biomechanical Foot Orthotics: A Retrospective Study. The Journal of Orthopaedic and Sports Physical Therapy, 1985, p. 205-209.
6. DONATELLI, R.: An In House System for Fabrication of Functional Orthotics. Newsletter Orthopaedic Division of Canadian Physiotherapy Association, Oct., 1989, 49-50.
7. DIGIOVANNI, J. E., & S. D. SMITH.: Normal Biomechanics of the Adult Foot. J. Am. Podiatr. Med. Assoc. 66: 812-824, 1976.
8. ENGSBER, J. R. & J. G. ANDREWS: Kinematic Analysis of the Talocalcaneal Tolocrural Joint During Running Sport. Medicine and Science in Sports and Exercise, 1987, Vol. 19, No. 3, p. 275-283
9. GOULD, J. A., G. J. DAVIES.: Orthopaedic and Sports Physical Therapy. Mosby 1985, p. 313-341.
10. HERZOG, W., B. M. NIGG, L. J.: READ, & E. OLSSON. Asymmetries in Ground Reaction Force Patterns in Normal Human Gait. Medicine and Science in Sports and Exercise, Vol. 21, No. 1, p. 110-114.
11. LATTANZA, L., G. W. GRAY, R. M. KANTHER.: Closed Versus Open Kinismatic Chain Measurements of Subtalar Joint Eversion: Implication for Clinical Practice. Newsletter Orthoppaedic Division, Canadian Physioterapy Asotiation, Oct. 1989, p.4-6.
12. LEES, A. & P. J. MCCULLAGHA.: A Premilinary Investigation into the Shock Absorbency of Running Shoes and Shoe Inserts. Journal of Human Movements Studies, 1984, 10 95- 106.
13. LINTON, M. & GALL, P.: The Practical Statistician. Brooks Cole 1975 p. 112-114.
14. MACREA, J. D.: Pediatric Orthopaedics of the Lower Extremity. New York: Futura, 1985.
15. ORTHOFEET ORTHOTIC SYSTEMS Instructional Manual. Hillsdale N. J. 1987.
16. ROOT, M. L., W. P. ORUEN, & J. N. WEED.: Clinical Biomechanics, Vol. II: Normal and Abnormal Function of the Foot. Los Angeles: Clinical Biomechanics Corp. 1977.
17. ROOT M. L., W. P. ORIEN, & R. L. HUGHES.: Biomechanical Examination of the Foot. Vol. I, Los Angeles: Clinical biomechanics Corp,1971.
18. ROSE,G. K.: Correction of the Pronated Foot. J. Bone Joint Surgery (Am) 40: 674-683, 1958.
19. SCRANTON, P. E., L. R. PEDEGANA, & J. P. WHITESEL.: Gait Analysis. Alterations in support Phase Forces Using Supportive Devices. American Journal of Sports Medicine, 1982, Vol. 10, No. 1.20. SMITH, L. S., T. E. 20.
20. CLARKE, C. L. HAMILL, & F. SANTOPIETRO.: The Effects of Soft and Semi Rigid Orthotics Upon Rearfoot Movements in Running. Podiatric Sports Med. 76: 227-233, 1976.
21. STACOFF, A., J. DENOTH, KAELIN, E. STUESSI.: Running Injuries and Shoe construction: Some Possible Relationship. International Journal of Sport Biomechanics, 1988, 4, 342-357.