Effects of Ankle-Foot Orthoses on Ankle and Foot Kinematics in Patients With Subtalar Osteoarthritis

Yu-Chi Huang, MD, Kimberly Harbst, PhD, Brian Kotajarvi, MS, PT, Diana Hansen, BA, Matthew F. Koff, PhD, Harold B. Kitaoka, MD, Kenton R. Kaufman, PhD


Objective: To determine whether different foot orthoses have a similar effect on foot kinematics in subjects with subtalar osteoarthritis (OA) when walking on various ground conditions.

Design: Within-subject comparison study.

Setting: Biomechanics research laboratory.

Participants: Ten subjects with unilateral subtalar OA.

Interventions: Custom-made ankle foot orthosis (AFO), rigid hindfoot orthosis (HFO-R), and articulated hindfoot orthosis (HFO-A) were used by subjects walking on level, ascending, and descending ramp, and side slope conditions.

Main Outcome Measures: The triplanar range of motion of the calcaneus relative to tibia (hindfoot) and metatarsal relative to calcaneus (forefoot) was measured using an 8-camera motion analysis system when subjects with subtalar OA wore different foot orthoses.

Results: Braces tended to perform similarly in reducing motion of the forefoot and hindfoot for all ground conditions when compared with unbraced but wearing shoes. The AFO significantly restricted frontal plane hindfoot motion during ramp descent (P < .01) and on a side slope when the arthritic subtalar joint was higher than the unaffected side (P = .02). The HFO-A provided significant frontal plane hindfoot motion restriction during ramp descent (P < .01) and on a side slope when the arthritic subtalar joint was lower than the unaffected side (P = .03). The HFO-R significantly restricted frontal plane hindfoot motion in all ground conditions except ramp ascent (P < .05).

Conclusions: The HFO-R provides significant subtalar joint motion restriction while walking. The HFO-R may be considered an optimal orthosis for patients with subtalar OA pain arising from subtalar motion.

Key Words: Ankle; Foot; Kinematics; Orthotic devices; Osteoarthritis; Rehabilitation.

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SUBTALAR OSTEOARTHRITIS (OA) causes pain and stiffness located over the sinus tarsi area while walking on uneven surfaces.1,2 Nonsurgical methods for treating arthritic pain include activity modifications, nonsteroidal anti-inflammatory medications, intra-articular steroid injections, shoe modifications, ambulatory aids, and ankle-foot orthoses (AFOs).3-4 The major goal of an AFO is to control motion and bony alignment of the OA joint(s) and to reduce OA pain.1,3-7

Previous studies have evaluated the effect of AFOs on gait in healthy, able-bodied subjects and patients with rheumatoid arthritis (RA). Hunt et al8 described a hindfoot orthotic design for treating ankle and subtalar arthritic joint pain in patients with RA. Nester et al9,10 quantified the effects of foot orthoses that restricted either supination or pronation on kinematics and kinetics during gait of healthy, able-bodied subjects. Woodburn et al11,12 demonstrated that intervention with foot orthoses resulted in pain reduction and deformity correction for RA patients. Kavlak et al13 evaluated the positive effect of foot orthoses on pain relief, improved step and stride length, and reduction of energy expenditure in patients with RA. Thompson et al14 used orthotic therapy to treat pedal OA patients with pain. They concluded that OA patients could get longer pain relief by wearing orthotic devices. Huang et al15 studied the effect of foot orthoses on foot kinematics in patients with ankle osteoarthritis. None of these previous studies have quantified ankle-hindfoot and forefoot motion restriction imposed by different types of foot orthoses during gait in patients with subtalar OA.

The purpose of this study was to evaluate the triplanar range of motion (ROM) restriction in patients with subtalar OA who wore 3 different types of AFOs (custom-made AFO, rigid hindfoot orthosis [HFO-R], articulated hindfoot orthosis [HFO-A]) compared with wearing a shoe without an orthosis (unbraced) and walking over various ground conditions. We hypothesized that these orthotic devices provided a similar ROM restriction of the ankle and foot. The results from this study may be useful for clinical decision making concerning the optimal orthosis for treating patients with OA pain related to subtalar motion.

METHODS

Participants

We enrolled ten subjects in this study (5 men, 5 women; mean age, 51 ± 17y; range, 19–68y): 9 subjects had posttraumatic subtalar OA and 1 subject had idiopathic degenerative subtalar OA. All subjects were diagnosed with unilateral subtalar OA and no concomitant OA in any other lower-extremity joints. The diagnosis was made by clinical symptoms and radiographic findings with osteophytes and joint space narrowing. All subjects were referred from physicians in the Department of Orthopedic Surgery at Mayo Clinic. Patients who had previous arthrosis, lower-extremity joint replacement, or other systemic or neuromuscular disorders affecting gait were excluded from this study.

From the Orthopedic Motion Analysis Laboratory, Division of Orthopedic Research, Mayo Clinic Rochester, MN (Huang, Harbst, Kotajarvi, Hansen, Koff, Kitaoka, Kaufman); and Department of Physical Medicine and Rehabilitation, Chang Gung Memorial Hospital, Kaohsiung, Taiwan (Huang).

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Reprint requests to Kenton R. Kaufman, PhD, Orthopedic Motion Analysis Laboratory, Mayo Clinic, 200 First St SW, Rochester, MN 55905, e-mail: kauflman.kenton@mayo.edu.

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Procedures

We tested the subjects over the following ground conditions: walking on a level surface of 10-m length, ascending and descending a 10° ramp of 2.4-m length, walking on a 10° side slope of 6-m length having the ankle with arthritis lower than the unaffected side (side slope-low), and walking on the 10° side slope having the ankle with arthritis higher than the unaffected side (side slope-high). Two subjects were only tested over level surfaces because it was too painful for these 2 subjects to walk over the other 4 ground conditions. All subjects wore a standard shoe either without an orthosis or while wearing an AFO within the shoe. The orthoses tested in this study were: a solid AFO, an HFO-R, and an HFO-A (fig 1). All orthoses were custom-made for each subject by a certified orthotist. The proximal trim line of the AFO was inferior to the popliteal fossa and the distal trim line was proximal to the metatarsal heads. The proximal trim line of the HFO-R was inferior to the bulk of the gastrocnemius muscle bellies and distal trim line at the distal end of the heel fat pad. The proximal trim line of the HFO-A was inferior to the bulk of the gastrocnemius muscle bellies but the distal trim line was proximal to the metatarsal heads. The HFO-A used a Tamarack hinge. The anterior trim line for the AFO was anterior to the apex of the malleoli and for the HFO-R was at the midpoint of the malleoli. These trim lines are considered standard for these orthoses. Objective gait analysis for each ground condition and shoe-orthosis condition was performed on each subject. The gait analysis methods have been described previously.15 The order of testing of the shoe-orthosis combinations (unbraced shod, AFO, HFO-A, HFO-R) and ground conditions (level, ramp-up, ramp-down, side slope-high, side slope-low) was randomized.

Data Analysis

We used custom software to calculate the 3-dimensional kinematics. Eulerian angles were calculated to express joint orientation in a sequence-independent and clinically relevant form using relative rotation matrices.16,17 This joint coordinate system was used to express angular motion of the hindfoot (calcaneus relative to the tibia) segment (fig 2).

RESULTS

Our statistical analysis found that no single orthotic device consistently constrained the hindfoot ROM in all planes while not impeding forefoot ROM for each ground condition. The following paragraphs give the results of the statistical analysis for each ground condition. The total joint ROMs of the hindfoot and forefoot segments are given in figures 3 through 7. Each figure displays the ROM (average ± standard deviation [SD]) of the 2 segments for the sagittal, frontal, and transverse planes, for each orthosis and a ground condition. The results from the post hoc Student-Neuman-Keuls tests are displayed on the figures if significance was found.

Level Ground Condition

When walking over level surfaces (see fig 3A), the sagittal plane hindfoot motion was similar in the HFO-R and AFO, both of which were significantly less than the unbraced standard shoe and HFO-A (P less than .001). The standard shoe provided significantly less sagittal plane hindfoot motion than the HFO-A (P less than .001). The HFO-R significantly restricted the frontal plane hindfoot motion relative to the standard shoe (P less than .035). No significant differences were found in the transverse plane hindfoot motion among the shoe-orthosis conditions. The HFO-R allowed the greatest sagittal plane forefoot motion while walking over level surfaces (P less than .001). No significant differences were found in frontal and transverse plane forefoot motion among the shoe and orthoses (see fig 3B).
Ramp-Descending Ground Condition

When walking down the ramp, the AFO significantly restricted sagittal plane hindfoot motion compared with the unbraced standard shoe and HFO-A (P = .005). All orthoses significantly reduced frontal plane hindfoot motion relative to the shoe only (P = .004) (see fig 4A). No significant differences were found in transverse plane hindfoot motion among the shoe-orthosis conditions. The HFO-R provided significantly larger sagittal plane forefoot motion than the HFO-A (P = .036). No significant differences were found in the frontal and transverse plane forefoot motion among the shoe-orthosis conditions (see fig 4B).

Ramp-Ascending Ground Condition

When walking up the ramp, the sagittal plane hindfoot motion of the HFO-R and AFO were similar and significantly less than the HFO-A (P = .004). The AFO also significantly restricted sagittal hindfoot motion compared with the unbraced standard shoe (P = .004). The HFO-R and AFO significantly restricted frontal plane hindfoot motion when compared with the standard shoe (P = .023) (see fig 5A). No significant differences were found in the transverse plane hindfoot motion and in the triplanar forefoot motion among the shoe-orthosis conditions (see fig 5B).

Side Slope Having the Arthritic Ankle Higher Than the Normal Side

In the side slope-high condition, the AFO and the HFO-R significantly restricted sagittal plane hindfoot motion when compared with the HFO-A (P = .005). The AFO also significantly restricted sagittal hindfoot motion compared with the unbraced standard shoe (P = .004). The HFO-R and AFO significantly restricted frontal plane hindfoot motion when compared with the standard shoe (P = .036). No significant differences were found in the frontal and transverse plane hindfoot motion and in the triplanar forefoot motion among the shoe-orthosis conditions (see fig 6B).

Side Slope Having the Arthritic Ankle Lower Than the Normal Side

In the side slope-low condition, the sagittal plane hindfoot motion for the HFO-R and AFO conditions were similar and significant differences were found in transverse plane forefoot motion among the shoe-orthosis conditions (see fig 5B).
significantly less than that of the unbraced standard shoe and HFO-A conditions \((P<.001)\). The HFO-R and HFO-A significantly reduced frontal plane hindfoot motion compared with the standard shoe \((P=.031)\). No significant differences were found in the transverse plane hindfoot motion among the shoe-orthosis conditions (see fig 7A). The HFO-R provided the greatest sagittal plane forefoot motion \((P<.001)\). No significant differences were found in the frontal and transverse plane forefoot motion among the shoe-orthosis conditions (see fig 7B).

**Orthosis Versus Unbraced Hindfoot Motion**

In the level condition (see fig 3), the HFO-R was the only tested orthoses that provided significant frontal plane hindfoot motion restriction relative to the unbraced shod condition while walking on level surfaces. In the descending ramp condition (see fig 4), all orthoses provided significant frontal plane hindfoot motion restriction relative to unbraced shoe. The AFO significantly restricted sagittal plane hindfoot motion compared with the unbraced shoe. In the ascending ramp condition (see fig 5), no significant frontal plane hindfoot motion restriction was founded in all tested orthoses. In the side slope-high condition (see fig 6), the HFO-R and AFO significantly restricted the frontal plane hindfoot motion relative to unbraced, but the AFO significantly restricted the sagittal plane hindfoot motion. In the side slope-low condition (see fig 7), the HFO-R and HFO-A significantly restricted the frontal plane hindfoot motion relative to unbraced, but the HFO-R also significantly restricted the sagittal plane hindfoot motion compared with the unbraced shoe.

**DISCUSSION**

A primary symptom in patients with subtalar OA is pain and tenderness over the sinus tarsi or lateral hindfoot.\(^5\)\(^,\)\(^18\) The arthritic pain has 2 major sources: axial loading from heel strike to heel off and impingement of osteophytes which limit functional ROM of the affected joints.\(^1\) The subtalar joint provides inversion and eversion (frontal plane) motion of the hindfoot helping the foot to walk on uneven terrain.\(^1\)\(^,\)\(^2\) Therefore, it is often more painful and difficult for patients with subtalar OA to walk on uneven surfaces than on level surfaces.\(^1\)\(^,\)\(^2\)

**Fig 6.** The sagittal, frontal, and transverse planes ROM of the (A) hindfoot and (B) forefoot in subtalar OA patients using 3 types of orthoses when walking on the side slope-high condition. NOTE. Values are average ± SD. *Significant difference \((P<.05)\).

**Fig 5.** The sagittal, frontal, and transverse planes ROM of the (A) hindfoot and (B) forefoot in subtalar OA patients using 3 types of orthoses when walking up the ramp. NOTE. Values are average ± SD. *Significant difference \((P<.05)\).
The pain in patients with hindfoot OA may be treated effectively by using an AFO. An AFO restricts motion of the arthritic joint(s) during ambulation. The motion reduction avoids contact of osteophytes that lead to pain. In this study, we measured the kinematics of patients with subtalar OA walking on 5 types of ground conditions while wearing an orthosis or not braced but wearing shoes. We compared hindfoot and forefoot motion between the orthoses and unbraced shod conditions to determine which orthosis could selectively restrict subtalar joint motion.

Previous studies have only demonstrated the effect of an AFO on static stability. Raikin et al determined the effect of different casts and braces on the ankle and hindfoot immobilization using a prosthetic model. They reported that a custom-molded AFO provided the best sagittal and frontal plane motion resistance for the ankle and hindfoot. Eils et al evaluated different types of ankle braces in patients with chronic ankle instabilities. The results showed that all tested ankle braces provided significant triplanar hindfoot ROM restriction compared with the unbraced shod condition for both passive and rapidly induced instabilities. Similarly, we found that an AFO provided good sagittal plane hindfoot motion restriction in all ground conditions and also provided significant frontal plane hindfoot motion restriction when walking down a ramp and during the side slope-high conditions. However, no significant transverse plane hindfoot motion restriction occurred when using the AFO in our study.

Similar studies have been conducted in asymptomatic healthy, able-bodied subjects and patients with unilateral ankle OA. The subjects wore the same types of AFOs used in this study. In Kitaoka et al’s study, healthy, able-bodied subjects walked over a level surface. The results indicated that all orthoses limited sagittal and coronal hindfoot motion with the AFO providing the greatest motion control. At the midfoot, the HFO-A provided the greatest stabilization with the HFO-R allowing the most motion. This study of subjects with unilateral ankle OA was expanded to include alternative ground conditions that were the same as used in the present study. The HFO-A restricted motion of the unaffected joint and did not effectively restrict hindfoot motion. The AFO and HFO-R provided greater stabilization. The HFO-R was considered to be the best option because it provided select restriction to the ankle hindfoot motion but also allowed sufficient forefoot motion compared with the AFO. In the present study, only the HFO-R significantly restricted the frontal plane hindfoot motion compared with the unbraced shod condition when walking over a level surface for subjects with subtalar OA. Additionally, the HFO-R allowed more sagittal plane forefoot motion relative to the unbraced shod condition.

It must also be noted that each orthotic device has its own specialized design, which will influence the degree of immobilization of the arthritic and adjacent joints. In this study, the HFO-A allowed more sagittal plane hindfoot motion than the AFO and HFO-R. The bilateral hinges of the HFO-A, located proximal to the calcaneus, play a key role in allowing more normal sagittal plane hindfoot motion than fixed orthoses. The HFO-R provided better forefoot motion than the other tested orthoses in most ground conditions. This result may be explained by the longer footplates of the AFO and HFO-A, extending to the metatarsal heads, which may influence forefoot function.

We consider an orthotic device that limits the ROM of the arthritic joint(s) but allows a normal ROM of nonarthritic joint(s) to be an ideal orthosis for treating patients with subtalar OA pain arising from subtalar motion. For people with subtalar OA pain related to joint motion, we consider the best orthosis to be one that not only limits the inversion and eversion function of the hindfoot but that also allows full ROM of the unaffected joints. Based on our results, the HFO-R is the only brace that provided significant subtalar joint motion restriction while walking over level surfaces (see fig 3). While walking down the ramp (see fig 4), the HFO-R and HFO-A selectively restricted the subtalar joint motion and the HFO-R provided greater sagittal plane forefoot motion than the HFO-A. Unfortunately, no orthosis that we tested could limit subtalar joint motion in patients with subtalar OA when ascending the ramp (see fig 5). In the side slope-high ground condition (see fig 6), only the HFO-R selectively restricted subtalar joint motion without impeding other joint motion. The HFO-A provided significant subtalar joint motion restriction without impeding other joint motion in the side slope-low ground condition (see fig 7). While descending the ramp and walking on the side slope-high condition (see figs 4, 6), the AFO allowed significant subtalar joint motion, but also significantly restricted sagittal plane hindfoot motion at the same time.
We suggest that the HFO-A is a good option when walking over the side slope-low condition only and the HFO-R may be considered a good option when walking over ground conditions (level, descending ramp and side slope-high conditions) for treating patients with subtalar OA pain related to subtalar motion. However, we found that the AFO may not be the optimal orthotic device for patients with subtalar OA pain during walking over various ground conditions. Most people walk on level or ramped conditions but rarely walk on side slope conditions. Therefore, we recommend the HFO-R as the optimal orthosis for patients with subtalar OA pain arising from subtalar motion. The results of this study can be used to offer objective evidence to clinicians of which orthosis can provide better restriction to the subtalar joint and less restriction to the unaffected joints when treating patients with subtalar OA pain.

CONCLUSIONS

This study investigated the effects of 3 different orthoses on 3-dimensional motion of the hindfoot and forefoot while subjects walked over 5 different ground conditions. The HFO-R was the only orthosis that consistently restricted hindfoot motion while allowing forefoot motion. Based on this data, the HFO-R may be considered an optimal orthosis for patients with subtalar OA pain arising from subtalar motion.

References