Site-Specific Loading at the Fifth Metatarsal Base in Rehabilitative Devices: Implications for Jones Fracture Treatment

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Background: Fractures of the fifth metatarsal base are a relatively common injury. Whether treated surgically or nonsurgically, injury rehabilitation typically involves immobilization in a rigid sandal or short controlled ankle movement (CAM) walker boot.
Objective: To determine the peak pressure, contact pressure, and impulse at the base of the fifth metatarsal in 3 common footwear devices during common gait activities.
Design: This was a retrospective comparative study.
Setting: Research was conducted in a sports performance laboratory at a university.
Participants: Twenty subjects without a recent history of foot injuries volunteered to participate.
Methods: Each subject performed 3 common gait activities (walking, heel walking, and pivoting) in 3 footwear devices (short CAM walker boot, postoperative sandal, running shoe). Pressure data were sampled (100 Hz) using individually sized plantar pressure insoles and software (Tekscan). Walking trials were collected at 1.0 m/s ± 5% (FusionSport Timing Gates).
Outcome Measurements: Peak pressure, contact pressure, and impulse at the fifth metatarsal base region were determined for all trials for all subjects. Mixed-effect regression models were used to compare pairwise differences in outcome variables between footwear devices.
Results: The CAM walker boot resulted in significantly lower peak pressure at the fifth metatarsal during walking and heel-walking relative to the postoperative sandal ($P < .01$) and during heel-walking ($P < .01$) relative to the standard athletic shoe. The CAM walker boot significantly reduced contact pressures at the fifth metatarsal during walking and heel-walking relative to the postoperative sandal ($P < .01$), and during heel-walking relative to the standard athletic shoe ($P < .001$).
Conclusions: Our results suggest that the short CAM walker boot more effectively off-loads the fifth metatarsal during common gait activities than a postoperative sandal or a standard athletic shoe. A short CAM walker boot may be a beneficial rehabilitative tool for patients undergoing rehabilitation after treatment of Jones fractures and other base of fifth metatarsal fractures.

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INTRODUCTION

Fractures of the fifth metatarsal base are a relatively common injury, particularly in active populations. These include fractures of the metaphysis (ie, Jones fractures), and avulsion fractures from the base of the fifth metatarsal (ie, dancers fracture) [1]. Although both types of fracture can occur acutely, Jones fractures often occur with clinical and radiological characteristics of overuse (ie, stress) fractures. Jones fractures in athletes are most often treated surgically, as nonsurgical management results in a high incidence of non-union [1-5]. However, nonsurgical treatment can produce successful results for certain injuries and in some populations [6]. Avulsion fractures typically are successfully treated nonoperatively [7].

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A primary goal of rehabilitation after treatment of a fifth metatarsal fracture, whether nonoperative or operative, is to reduce loading of the lateral foot and fifth metatarsal while avoiding periods of prolonged cast immobilization, which can lead to muscle atrophy and deconditioning [8]. The optimal postoperative or rehabilitative device would allow the patient to ambulate without assistance, protecting the fifth metatarsal from excessive loads. Common devices used during rehabilitation include a rigid, wooden-sole postoperative sandal (sandal) or a controlled ankle movement (CAM) walker boot (boot) (Figure 1). The magnitude and distribution of force at the base of the fifth metatarsal in these devices has important implications toward modifying pathomechanics and optimizing rehabilitation during treatment of proximal fifth metatarsal fractures [9]. The peak pressure, contact pressure, and impulse at the fifth metatarsal during normal gait activities in a CAM boot, sandal, and shoe are currently unknown.

Recent clinical studies have demonstrated little difference in clinical outcomes in various orthotics including elastic wrap, open-toed shoes, short-leg orthoses, and crutches in the nonoperative treatment of fifth metatarsal fractures in patients in whom time to return to full activities was not critical [10,11]. Nevertheless, in the treatment of patients hoping to return to full activity sooner (athletes, military personnel), an understanding of the biomechanical differences in various rehabilitation devices may guide treatment decisions.

Figure 1. Photograph of the CAM walker boot and rigid postoperative sandal used in this study.

Plantar pressure distributions in various shoe devices have been investigated using pressure-mapping systems [12,13]. These systems generally consist of a thin film insole that fits into the shoe and is fitted with multiple pressure sensors. Sports scientists commonly use pressure mapping to compare the effect of different shoe types and movement patterns on the plantar pressure [14,15]. It has been suggested that pressure insole technology might change the state of prescription of therapeutic shoes, braces, and orthoses [16], as it gives clinicians an objective measurement of the load on the foot. Plantar pressure measurements have been used to investigate the efficacy of treatments for osteoarthritis [17,18]. Brophy et al [19] also used pressure mapping systems to examine the risk factors for turf toe, and found that patients with a history of turf toe injury had higher great toe plantar pressures. Kavros et al [12] recently concluded that off-the-shelf rocker-bottom provisional footwear with plastizote are effective at reducing the mean peak plantar pressure at the GT. In addition, using pressure-mapping systems, rocker sole shoes are well documented in literature to reduce forefoot pressure [20-22]; however, to our knowledge, this is the first study to compare a running shoe, a CAM boot, and a postoperative sandal under various movement conditions.

The goal of the present study was to determine the peak pressure, contact pressure, and impulse (force-time integral) at the fifth metatarsal during 3 movement tasks in 3 different devices: a rigid postoperative sandal, a CAM walker boot, and a standard athletic shoe (shoe). We hypothesized that a CAM walker boot would result in lower peak pressure, contact pressure, and impulse at the fifth metatarsal compared to those with other devices. The goal is to implement a rehabilitative device that will reduce pressure at the fracture site while minimizing the risks associated with prolonged non–weight bearing.

METHODS

After obtaining approval from our institutional review board, we recruited 10 healthy males and 10 healthy females to participate in this study. The age of participants ranged from 19 to 38 years. All subjects were confirmed free of lower extremity injury for at least 1 year before participation, had never been treated for a major foot injury, and did not require or use orthotic devices. Data were collected on each subject's self-defined dominant foot. Of the 20 subjects in our study, 19 self-defined themselves as right-foot dominant, whereas 1 subject self-defined as left-foot dominant.

Foot Assessment

A physical therapist examined the dominant foot of each subject and classified the mobility of each subject's foot as hypermobile, hypomobile, or normal based on the relative mobility of the foot in full inversion or eversion of the calcaneus [23]. Hypermobility was specified if the midfoot became more rigid with an inverted calcaneus, whereas hypomobility was specified if the midfoot became more rigid with an everted calcaneus. Finally, hallux dorsiflexion and plantarflexion, as well as ankle dorsiflexion and plantarflexion excursion, were measured for each subject's dominant foot before participation in the movement tasks.

Pressure Sensors

Plantar pressure measurements were obtained using a commercially available measuring system (Tekscan Inc, South Boston, MA) with custom sensor insoles. The Tekscan sensor system has been used extensively in biomechanics research and has been validated as a reliable data collection tool [24-27]. Before use, each insole was trimmed to fit the size of the subject's foot. Each sensor insole contained 960 sensors arranged in rows and columns. After the insole was sized appropriately, it was placed into each of the 3 devices for testing. The 3 foot devices tested included a CAM walker boot (Integrity V Wlkr Lt Air, Biomet Bracing, Parsippany, NJ), a postoperative hard-sole sandal (Darco, Biomet Bracing, Parsippany, NJ), and a standard running shoe (subject's own selected running shoe) (Figure 1).

Data Acquisition

Data collection was performed in a controlled clinical laboratory setting. Before performing the movement tasks, each subject was taken through a step calibration protocol as defined by Tekscan [28]. For calibration, each subject was asked to stand on a single leg with full weight bearing on the insole in each foot device. Tekscan was used to sample data from the dominant foot at 100 Hz.

Gait Tasks

All subjects performed 3 normal gait tasks, namely, level walking, heel walking, and pivot turns, in each of the 3 devices. Each subject performed 5 successful trials of each movement in each foot device, for a total of 45 trials. Trials were considered successful if the movement was performed appropriately at the correct speed. Smart Speed motion sensor lights (Fusion Sport, New Zealand) were used to record time for each walking movement and to ensure that walking speeds across trials were consistent. The total walkway distance was 20 ft, with timing gates spaced 10 ft apart. Subjects were asked to perform the movement tasks in random order. (1) During level walking, subjects walked in a straight line at a standard pace of 1.0 m/s $\pm$ 5%. Walking speed was selected based on previous gait studies. (2) During heel walking, subjects walked on their heels at 1.0 m/s $\pm$ 5%, and were instructed to attempt to keep pressure off the hallux and forefoot. (3) During pivot turns, each subject performed 3 consecutive, 90° heel pivot turns on the dominant foot.

Pressure Analysis

Plantar pressure data were analyzed using Tekscan software. Pressure data, rather than force data, were reported because the insole system directly measures pressure data and derives force data secondarily. Each trial movie was separated into stance phases using Tekscan's Peak/Stance function. "Heel-strike" was defined as the point at which the sensors recorded a minimal pressure, and "toe off" was defined as the point at which the sensors were unloaded and the recorded pressure returned to baseline. The foot strike recorded in the middle of the collection time was extracted and divided into regions using standard Tekscan templates and individual data export boxes. The region of interest in the present study was the fifth metatarsal base (MT5). For each analyzed foot strike, peak pressure (highest pressure in a 2 $\times$ 2 box of sensors, in kPa), contact pressure (average pressure in the entire region of sensors, in kPa), and impulse (absolute force time-integral, in N*s) were exported. The contact pressure was the highest pressure seen over the entire region bounded by the regional box (eg, MT5). Impulse was calculated as the product of the force (gathered indirectly from pressure and surface area readings) and the time over which the force was applied in each region.

Statistical Analysis

For each test, trials 1 and 5 were discarded and the middle 3 trials were selected for data analysis. This was performed to eliminate variation in trial data due to wearing the device for the first time (first trial) or wearing the device for an extended period of time (fifth trial). Means and standard errors (SE) were calculated for all device conditions (short CAM boot, postoperative sandal, running shoe) and movements (heel, pivot, walking) for a total of 9 conditions for each subject. Mixed-effects regression models were used to estimate mean simultaneous pairwise differences and 95% confidence intervals among the 9 conditions.

RESULTS

Study Patients

A total of 20 healthy subjects were recruited. The subjects' age range was 19 to 38 years, and their weight ranged from 48.0 to 94.8 kg. Of the 20 subjects, 17 were found to have normal midfoot mobility, whereas 3 subjects were classified as having increased midfoot mobility (hypermobility). No subjects were classified as hypomobile. All 20 subjects successfully completed 5 trials of each movement activity in each foot device. The middle 3 trials from each subject were analyzed for peak pressure, contact pressure, and impulse, as previously described (Table 1). Ninety-five percent confidence intervals for mean pressure, contact pressure, and impulse for each of the 3 rehabilitation devices are graphically displayed in Figure 2.

Peak Pressure

The CAM walker boot resulted in significantly lower peak pressure at the fifth metatarsal during walking and heel-walking movement activities relative to the postoperative sandal ($P < .01$) and during heel-walking ($P < .01$) relative to the standard athletic shoe (Table 2). There was a trend toward lower peak pressure in the boot relative to the standard athletic shoe during walking ($P = .078$) (Table 2).

Contact Pressure

The CAM walker boot showed significantly reduced contact pressures at the fifth metatarsal during walking and heel-walking relative to the postoperative sandal ($P < .01$), and during heel-walking relative to the standard athletic shoe ($P < .001$) (Table 2).

There was no significant difference in mean peak pressure between the postoperative sandal and the standard running shoe during all 3 activities (Table 2).

DISCUSSION

Postoperative rehabilitation after Jones fractures and fifth metatarsal avulsion fractures involves immobilization of the foot and ankle to off-load the lateral foot during ambulation. Prolonged casting is suboptimal during Jones fracture rehabilitation, as this can lead to muscle atrophy and deconditioning [8,29]. Our results indicate that both peak pressure and contact pressure were significantly lower in the boot device compared to both other devices. The use of a CAM walker boot may be superior to a postoperative sandal during treatment and rehabilitation after fractures of the fifth metatarsal base, once weight bearing is allowed.

In addition to offloading the fifth metatarsal in common gait movements, a CAM walker boot has several potential advantages during foot fracture rehabilitation. The CAM boot immobilizes the ankle joint and extrinsic tendons, including the peroneal tendons, while allowing device removal for motion and resistance exercises to reduce the risk of muscle atrophy and deconditioning seen with prolonged casting [7,8]. Disadvantages of the boot include relative bulk and weight compared to postoperative sandals and athletic shoes, which can create discomfort for patients, difficulty wearing long pants, and potential strain at proximate joints (ie, knee and low back). Many boots also have a foot plate that is higher than a standard shoe, creating a functional limb length inequality. This can result in gait alterations and proximate joint symptoms.

During athletic activity, several factors influence the loads seen at the fifth metatarsal base. Foot alignment, dynamic force loading, and muscle activity of peroneus brevis each contribute to fifth metatarsal loads and susceptibility to stress fractures [30,31]. As the bone is loaded, dynamic remodeling of the bone occurs. This physiological process is mediated by activity of osteoclasts and osteoblasts

Table 1. *Summary statistics for footwear devices*

	Walk		
	Boot	**Sandal**	**Shoe**
Mean peak pressure (95% CI), kPa	181.7 (156.9-206.4)	279.9 (230.4-329.5)	236.1 (193.5-278.7)
Mean contact pressure (95% CI), kPa	90.2 (79.1-101.3)	134.6 (113.7-155.6)	110.6 (97.9-123.2)
Mean impulse (95% CI), Ns	32.9 (28.1-37.8)	41 (36-46)	37.9 (32.8-42.9)
	Heel Walk		
	Boot	**Sandal**	**Shoe**
Mean peak pressure (95% CI), kPa	148.2 (126.7-169.8)	285.7 (249.0-322.4	284.3 (233.5-335.1)
Mean contact pressure (95% CI), kPa	85.4 (72.3-98.6)	139.2 (121.0-157.4)	137.1 (121.4-153.9)
Mean impulse (95% CI),Ns	17.9 (14.4-21.4)	26 (22.6-29.4)	22.1 (19-25.2)
	Pivot		
	Boot	**Sandal**	**Shoe**
Mean peak pressure (95% CI), kPa	129.1 (112.8-145.3)	163.2 (144.5-181.9)	156.8 (138.3-175.3)
Mean contact pressure (95% CI), kPa	62.1 (55.6-68.6)	89.4 (79.8-99.0)	83.7 (73.8-93.7)
Mean impulse (95% CI), Ns	43.5 (38.6-48.4)	47.4 (40.6-54.1)	43.9 (38.1-49.7)

Summary statistics for plantar pressures in CAM walker boot (Boot), rigid sandal brace (Sandal), and standard athletic shoe (Shoe) during 3 common gait activities.

CI = confidence interval.

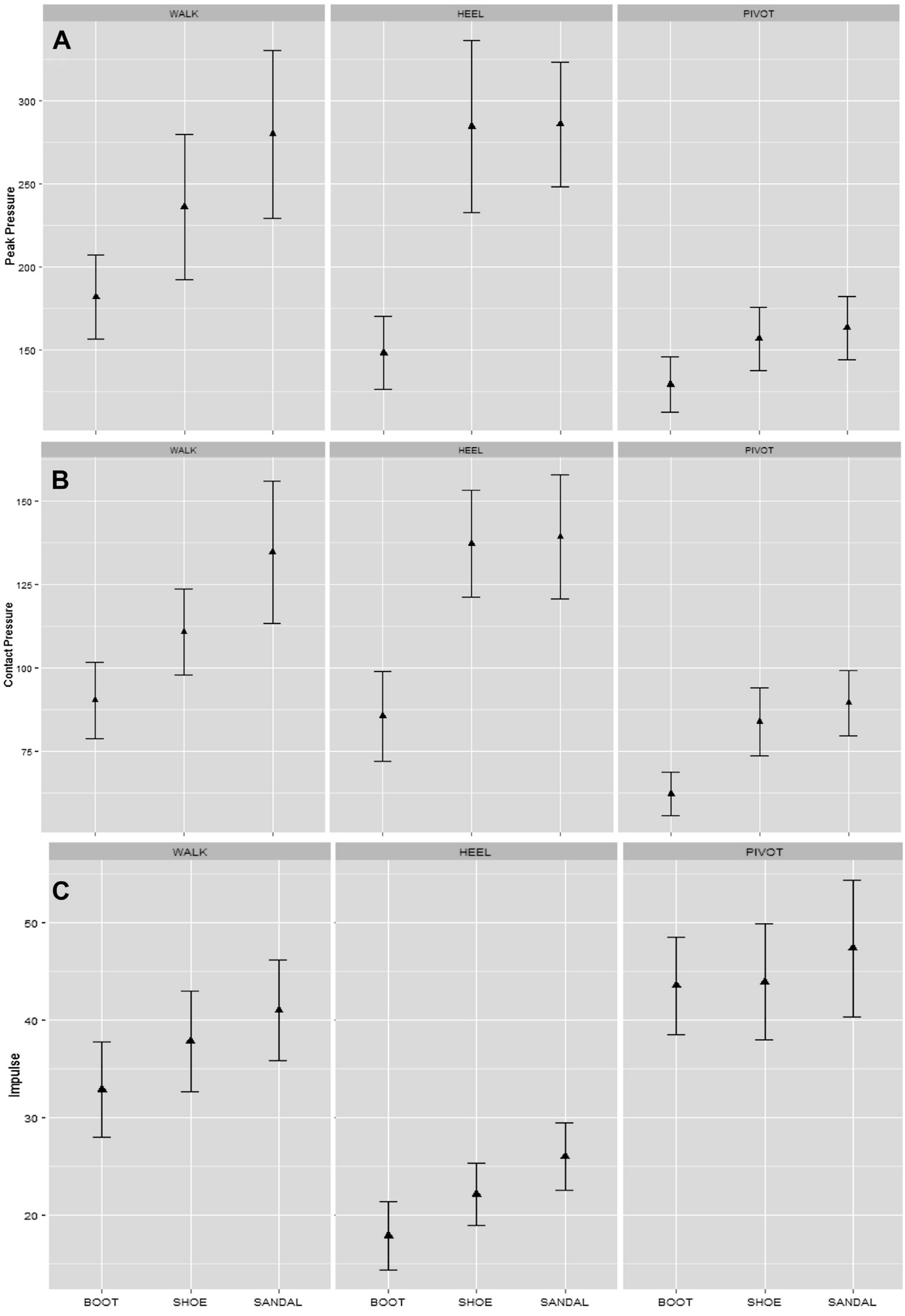

Figure 2. Graphic illustration of 95% confidence intervals of the mean (a) peak pressure, (b) contact pressure, and (c) impulse in 3 footwear devices in 3 gait activities. Peak pressure and contact pressure are given in kPa, impulse in Ns.

Table 2. *Pairwise comparison of footwear devices*

	Walk		
	Boot-Shoe	**Boot-Sandal**	**Shoe-Sandal**
Mean peak pressure difference (*P* value)	54.5 (.078)	98.3 (<.01)	43.8 (.30)
Mean contact pressure difference (*P* value)	20.4 (.065)	44.5 (<.001)	24.1 (.011)
Mean impulse difference (*P* value)	5.0 (.65)	8.11 (.064)	3.14 (.963)
	Heel Walk		
	Boot-Shoe	**Boot-Sandal**	**Shoe-Sandal**
Mean peak pressure difference (*P* value)	136.1 (<.01)	137.5 (<.01)	1.4 (1.00)
Mean contact pressure difference (*P* value)	51.7 (<.001)	53.8 (<.001)	2.1 (1.00)
Mean impulse difference (*P* value)	4.2 (.822)	8.1 (.066)	3.9 (.882)
	Pivot		
	Boot-Shoe	**Boot-Sandal**	**Shoe-Sandal**
Mean peak pressure difference (*P* value)	27.7 (.853)	34.2 (.647)	6.4 (.98)
Mean contact pressure difference (*P* value)	21.7 (.037)	27.3 (.0017)	5.6 (.99)
Mean impulse difference (*P* value)	.40 (.99)	4.1 (.853)	3.7 (.913)

Peak pressure and contact pressure in kPa, impulse in Ns. Mixed-effects regression models were used to determine *P* values corresponding to pairwise differences.

responsible for the resorption of old bone and deposition of new bone, respectively [32]. Periods of prolonged stress, as often occur in athletic populations during periods of extensive training, can shift the balance of bone remodeling toward bone resorption, thus weakening the bone. Biomechanical studies [9] of the fifth metatarsal suggest that the maximum pressure sustainable by a healthy fifth metatarsal before mechanical failure is roughly 1100 kPa, a value much larger than those observed in the present study and other studies examining fifth metatarsal pressure in athletic activity [33,34]. Prolonged periods of repetitive bone loading may sufficiently weaken the bone to the point at which much smaller forces and stresses are sufficient to cause a complete fracture. With this consideration, the differences in loads observed between the various rehabilitation devices in this study may be significant in the context of repetitive loading of a weakened bone. The goal of rehabilitation from injury is to reduce loading at the proximal fifth metatarsal, allowing bone healing.

Our data suggest that postoperative sandals are less effective than CAM boots in offloading the fifth metatarsal during ambulation, and may be no different from standard athletic shoes. Although the postoperative sandal may also alter gait mechanics, peak and contact pressures under the fifth metatarsal were not significantly reduced compared to those with a standard athletic shoe. The short CAM walker boot used in the current study uses a rocker sole to offload specific regions of the foot during ambulation. Unlike the boot, most postoperative sandals have a rigid sole and do not use rocker mechanics to aid in forefoot unloading during walking. Previous studies have shown that the design of rocker sole footwear can affect pressure distributions across the forefoot [35-38]. Certain shoes with rocker soles offload the medial and central forefoot at the expense of increasing the peak pressure in the lateral forefoot [39]. Our data support the notion that CAM boots with a rocker sole may effectively reduce the loading of the fifth metatarsal during common gait activities. The relative contribution of the CAM walker boot's rocker sole and ankle joint immobilization in unloading the fifth metatarsal during gait would benefit from further investigation. Specifically, it is unknown whether a sandal or shoe designed with a rocker sole would be equivalent to a boot in terms of offloading the fifth metatarsal.

A potential limitation of this study is that none of the subjects had been previously treated for a fifth metatarsal fracture. Jones fractures more commonly occur in patients with cavus and hindfoot varus, which results in excess loading of the lateral foot [30,31]. Some patients with Jones fractures have been noted to complain of lateral foot pain weeks before fracture [40]. It is likely that a combination of abnormal foot alignment, abnormal mechanics, and altered foot loading contribute to bone weakening before mechanical failure. It is possible that patients at risk for Jones fractures would demonstrate altered pressure distribution across the lateral forefoot during ambulation or other athletic activities. It is also important to note that this was an in-session analysis and the subjects did not wear the devices before the session. The subjects' gait patterns may change over a longer period of time as the subjects gain familiarly with the device. In addition, pressure of the contralateral foot remains unknown, as this study measured the pressure only on the tested foot. A patient wearing a CAM boot may experience gait changes on the contralateral limb, affecting the plantar pressure of this foot as well.

CONCLUSIONS

Rehabilitation after fifth metatarsal fractures involves a period of protection and off-loading of the bone to allow sufficient healing, then progression to weight bearing during ambulation. A key goal of rehabilitation is to offload the lateral forefoot during common gait activities while avoiding prolonged casting and periods of non—weight bearing. We demonstrate that peak pressure and contact pressure at the fifth metatarsal were significantly reduced during common gait activities with the use of a short CAM walker boot compared to a rigid sandal or athletic shoe. The rigid sandal and standard athletic shoe showed no significant difference in pressures at the fifth metatarsal during common gait activities. These results support the use of a short rocker-sole CAM walker boot during rehabilitation from fifth metatarsal fracture.

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CME Question

During which one of the following combinations of task and footwear was there a significant difference in the peak pressure at the fifth metatarsal when compared to a controlled ankle movement (CAM) walker boot?

a. walking and an athletic shoe
b. pivoting and a postoperative sandal
c. heel walking and a postoperative sandal
d. pivoting and an athletic shoe

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