FOOT & ANKLE INTERNATIONAL

The Effect of Ankle Position on Plantar Pressure in a Short Leg Walking Boot

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ABSTRACT

Short leg walking boots have been shown to be an effective alternative to total contact casting for the reduction of plantar pressure. Conventional theory indicates that placing the ankle in different positions may affect the plantar pressure and ultimately the healing time for a plantar ulcer. This study attempted to determine the changes in plantar pressures due to alterations in the position of the ankle angle in a walking boot. Thirteen healthy subjects were recruited and tested with an insole pressure measurement system. The result demonstrated that small changes in ankle position in dorsiflexion or plantarflexion have a significant impact on resulting forefoot and hindfoot plantar pressures while walking in a prefabricated boot.

Key Words: Cast; Plantar Pressure; Ulcer; Walking Boot

INTRODUCTION

Many studies have demonstrated that the total contact cast is an effective therapy for healing plantar neuropathic ulcers.[5,8,13] Various techniques for total contact casts have been described in the literature.[3–5,7,9] The purpose of a total contact cast is to diffuse the weightbearing function of the cast in order to reduce the concentration of high pressure in the area of the plantar ulceration. Ulcer healing has been reported to take an average of 6–10 weeks,[12–14] although this is subject to many variables. An alternative to this time-consuming, technically demanding, and costly treatment is the use of a removable walking boot.

Removable walking boots have been gradually introduced into the array of choices for a diabetic ulcer-healing regimen.[1,2,10,11] The many potential advantages to a removable walking boot include ease of application, reduced need for specialized training of medical personnel (compared to a total contact cast), the provision of a more consistent and reproducible therapy, and enhanced access to the ulcer itself when inspection, debridement, or topical therapy is required. This form of off-loading is also a useful alternative in patients who cannot tolerate being in a cast because of anxiety, who have had prior cast-related complications, or who have wounds with copious drainage. Several recent studies have compared removable walking boots to total contact casts. A study in 1997 by Baumhauer and colleagues tested the Aircast Pneumatic Walker against a total contact cast.[2] They concluded that the Aircast Walker effectively decreased peak plantar pressures and pressure–time integrals over five locations under the foot at least as well as or better than the total contact cast.

In 1999, Armstrong and Stacpoole-Shea compared total contact casts against the Aircast Pneumatic Walker and the Centec DH Pressure Relief Walker.[1] The researchers found that the total contact cast reduced peak pressures significantly better than the two removable walkers, but that the Centec Walker performed better than the total contact cast and the Aircast Walker in reducing pressure–time integrals.[2] The pressure–time integral incorporates both impulse and contact area in one equation, and a 1999 study by Sauseng et al. concluded that pressure–time integrals appear to be a valuable parameter for estimating the risk of ulceration in patients with diabetes.[11]

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A study by Conti et al. showed that conventional short leg casts provide unloading of plantar pressures similar to total contact casts.[6] In a study comparing pressures in the Bledsoe Conformer Diabetic Walking Boot to a short leg total contact cast,[10] the results demonstrated that the Bledsoe Conformer Boot reduced peak pressures in five regions better than the short leg total contact cast.[10] It also reduced the pressure–time integral under the entire foot by 23% when compared to the short leg cast.[10]

During preliminary studies with the Bledsoe Conformer Walking Boot, it was noted that small changes in the ankle position affected plantar pressure distributions. Conventional theory of cast application states that placing the ankle in slight dorsiflexion optimizes unloading of the forefoot and, conversely, that plantarflexion of the ankle increases pressures under the forefoot. In our preliminary work, we found the exact opposite, namely, that placing the ankle in slight dorsiflexion increased forefoot pressures. Therefore, we decided to test a larger number of subjects to investigate further this phenomenon of ankle position on plantar pressure distribution in a walking boot. We hypothesized that placing the ankle in dorsiflexion would increase forefoot pressures and that placing the ankle in plantarflexion would decrease forefoot pressures.

This current research reports on how the effects of ankle position in the Bledsoe Diabetic Conformer Boot can be used to optimize plantar pressure relief in the forefoot and hindfoot regions.

Fig. 1: The modified Bledsoe Diabetic Conformer Walking Boot used in the study. The small insert picture demonstrates the ankle adjustment mechanism.

MATERIALS AND METHODS

Thirteen healthy subjects, without any prior foot or ankle problems, were recruited for this study. There were five female and eight males, with an average weight of 64.5 ± 10.1 kg and an average height of 169.25 ± 9.1 cm. Plantar pressures were measured using the Novel Pedar™ in-shoe pressure measurement system (Novel, Munich, Germany). Data were collected at 50 Hz using 2-mm-thick capacitance insoles with 99 sensors per insole. Each insole also has an approximate sensor resolution of 1 sensor/cm^2, dependent on the insole size.

Custom-modified walking boots from Bledsoe Brace Systems (Grand Prairie, TX) were used in this study. The company's standard Conformer Diabetic Walking Boot was modified to allow an adjustable ankle angle. A hinge was added at the bottom of the upright supports of the boot to allow it to be set at various degrees of plantarflexion and dorsiflexion, in 2.5° increments (see Fig. 1). For this study, subjects were tested in three conditions: the standard neutral angle of a 90° angle between the foot and the tibia, 5° of plantarflexion, and 5° of dorsiflexion.

The order of testing conditions was randomly assigned for each subject. For each subject, proper boot size and insole size were determined, based on shoe size. The Novel Pedar™ insole was inserted into the walking boot, and the subject then donned the boot with the help of the researchers to assure proper fit. The subject then walked around in the boot for 5 minutes to become accustomed to the feel of the boot. Subjects walked at a self-selected velocity through the duration of testing. Data were collected for the first condition while the subject traversed a 10-m walkway five times. The boot was then adjusted to the second condition without removing the boot. The subject then walked around for 5 minutes again, in order to become accustomed to this second condition. Data were then collected in the same manner for the second condition. The boot angle was then adjusted to the third condition, and the identical process was repeated a third time. Fifteen steps for each condition for each subject were processed and analyzed. The pressure maps of each step were divided into three masks: hindfoot, midfoot, and forefoot. Peak

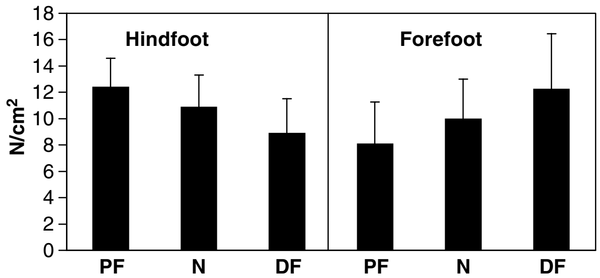

Fig. 2: Graph showing the peak pressure in both the forefoot and hindfoot for each of the three conditions.

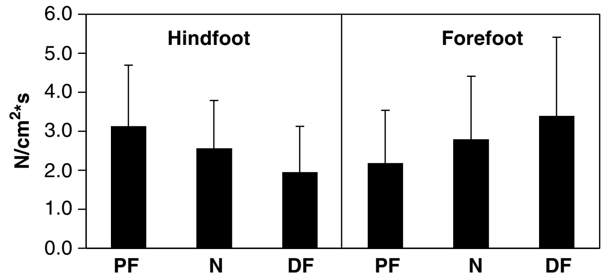

Fig. 3: Graph showing the pressure–time integral in both the forefoot and hindfoot for each of the three conditions.

plantar pressure and pressure–time integrals in each of these three areas and total contact time were compared among the three conditions with a one-way repeated measures analysis of variance (ANOVA) and a Tukey post hoc test, when appropriate.

RESULTS

Average contact time was not different among the three conditions. This is an indication that walking speed was constant among the three conditions for each subject.

Average peak forefoot pressure with the foot in neutral was 10.0 ± 3.0 N/cm^2, in the 5° plantarflexed position it was 8.1 ± 3.2 N/cm^2, and in the 5° dorsiflexed position it was 12.2 ± 4.2 N/cm^2 (see Fig. 2). Statistically, forefoot pressure in the plantarflexed position was significantly lower than in the neutral ($p = .01820$) and dorsiflexed ($p = .00013$) positions. The dorsiflexed position forefoot pressure was significantly higher than in the neutral ($p = .00480$) and plantarflexed ($p = .00013$) positions.

Average peak hindfoot pressure with the foot in neutral was 10.9 ± 2.4 N/cm^2, in the 5° plantarflexed position it was 12.4 ± 2.2 N/cm^2, and in the dorsiflexed position it was 8.9 ± 2.6 N/cm^2 (see Fig. 2). Statistically, hindfoot pressure in the dorsiflexed condition was significantly lower than the neutral ($p = .00018$) and plantarflexed ($p = .00012$) positions. The hindfoot pressure in the plantarflexed position was significantly higher than in the neutral ($p = .00181$) and dorsiflexed ($p = .00013$) positions.

Pressure–time integral is a measure of the combination of magnitude and duration of pressure. Average pressure-time integral in the forefoot with the ankle in neutral was 2.8 ± 1.6 N/cm^2/s, with the ankle plantarflexed it was 2.2 ± 1.4 N/cm^2/s, and with the ankle dorsiflexed, it was 3.4 ± 2.0 N/cm^2/s (see Fig. 3). The forefoot pressure–time integral with the ankle dorsiflexed was not significantly higher than in the neutral ($p = .05292$) position, but was higher than the plantarflexed position ($p = .000251$). The forefoot pressure–time integrals with the ankle in the plantarflexed position was not significantly lower than that of the neutral position ($p = .0512$).

Average pressure–time integral in the hindfoot with the ankle in neutral was 2.6 ± 1.2 N/cm^2/s, with the ankle plantarflexed it was 3.1 ± 1.6 N/cm^2/s, and with the ankle dorsiflexed it was 1.9 ± 1.2 N/cm^2/s (see Fig. 3). The hindfoot pressure–time integral with the ankle plantarflexed was significantly higher than in neutral ($p = .00481$) and dorsiflexed ($p = .000129$) positions. The hindfoot pressure–time integral with the ankle dorsiflexed was significantly lower than in the neutral ($p = .00216$) and plantarflexed ($p = .00013$) positions.

DISCUSSION

The results of this study confirm the preliminary findings in our research: first, that in healthy subjects, small changes in the ankle position can significantly alter pressure distribution on the plantar surface of the foot in a walking boot; second, that the increases and decreases of pressure that were measured are contrary to those predicted with standard cast theory. Consistent with our hypothesis, placing the ankle in a dorsiflexed position increases the pressure under the forefoot, while placing the ankle in a plantarflexed position decreases the forefoot pressure.

The exact opposite was found for the hindfoot. Placing the ankle in a 5° plantarflexed position increased both the pressure and the pressure–time integrals under the hindfoot. Placing the ankle in a dorsiflexed position decreased the hindfoot pressure and pressure–time integral.

These findings indicate that the Bledsoe Conformer Diabetic Walking Boot may be able to optimize the treatment of plantar ulcers in different areas of the foot by changes in ankle and hindfoot position. Based on these data, the counterintuitive suggestion is that dorsiflexing the ankle slightly may help with the healing of hindfoot ulcers, while plantarflexing the ankle slightly may help with the healing of forefoot ulcers.

While the empiric measurements clearly confirmed the preliminary findings of pressure reduction related to ankle position, the mechanism by which this occurs merits some consideration. One possible explanation for this phenomenon is that the change in ankle position within the walking boot changes the weightbearing line during gait, thus affecting the location of weightbearing pressure. This is made possible by the curved (''rockered'') surface of the sole of the boot. By this reasoning, the center of weightbearing pressure during gait shifts posteriorly as a result of the plantarflexed boot position, and this subsequently increases the pressure on the hindfoot and decreases the pressure underneath the forefoot area. Conversely, a dorsiflexed position of the boot shifts the center of weightbearing forward on the foot, and thus increases the pressure on the forefoot, and decreases the pressure underneath the hindfoot area.

These findings have implications for the treatment of neuropathic ulcerations in walking boots and possibly in total contact casts. Conventional theory holds that placing the ankle in slight dorsiflexion will help to decrease plantar pressure in the forefoot, thus possibly increasing the healing rate of a forefoot ulcer. Our results with healthy subjects and walking boots indicate the opposite is true. Further testing is necessary to discover whether the results from this study will extrapolate to total contact casting and also to determine if these changes persist over time as a patient becomes more accustomed to the orthoses. In addition, increasing the ankle angle may potentially increase shear forces which may be as detrimental as normal forces. The trade-off between reduced normal forces and the possibility of increased shear forces has not been determined and is beyond the scope of this study.

Practitioners who treat diabetic and neuropathic ulcerations in removable short leg walking boots need to be aware of the potential changes in plantar pressure as a result of the position of the ankle within the boot. Slight changes in dorsiflexion and plantarflexion can have significant effects on resulting plantar pressures, and thus on the efficacy of this treatment modality in achieving ulcer healing.

CONCLUSION

Our results agree with our hypothesis which stated that placing the ankle in a dorsiflexed position would increase forefoot pressure and that placing the ankle in a plantarflexed position would decrease forefoot pressure while walking in a prefabricated diabetic walking boot. While these results are valid for the healthy sample and the particular walking boot we tested, caution must be exerted when generalizing these results to the diabetic population or to a different brand of walking boot. Since we measured the immediate effects of altering ankle position on changes in forefoot pressure, we assumed that these effects would persist as subjects become more accustomed to the orthosis over time. Further research is required to test patients with diabetes to determine whether these changes in ankle position similarly affect plantar pressures in that clinical setting, and whether these changes persist over time and, ultimately, decrease the average healing time for plantar forefoot ulcers.

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