Walking Boot Design: A Gait Analysis Study

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This work was supported by a grant from Bledsoe Brace Systems Inc.

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ABSTRACT

This study investigated the effect of various short-leg walking boot designs on walking. Four commercially available walking boots and a synthetic walking cast were tested using three-dimensional gait analysis to determine their effect on a normal individual's gait pattern. Temporal-spatial parameters and lower limb kinematics and kinetics were analyzed for 10 normal subjects. The synthetic walking cast was the most different when compared with the shoe condition with respect to all the parameters tested. The Bledsoe walking boot was the only boot that was not significantly different from the shoe condition for all parameters tested.

Short lower-leg walkers have been designed as an alternative to traditional cast immobilization. The indications for use of lower-leg walkers include severe sprains, ankle and foot fractures, ad post-surgical stabilization after tendon or ligament repairs. These orthopedic walkers are light weight, convenient to use, and removable to perform range of motion exercises or inspect the injured extremity. Short-leg walkers are as effective as walking casts in healing ankle fractures, and patients treated with short-leg walkers experience significantly less edema, tenderness, and joint stiffness after 6 weeks of immobilization.[1]

In recent years, the cost of short-leg walkers has decreased substantially and even reached levels below the cost of synthetic or traditional plaster walking casts. The degree of immobilization is most likely more stringent in a cast; however, unless this is a requirement, the numerous advantages short-leg walkers have over casting make them appealing.

To date, no studies have investigated the effect short-leg walkers have on an individual's gait pattern. Previous studies have investigated only foot pressures in individuals wearing these orthoses.[2,3] Because these orthoses sometimes are worn for lengthy periods (up to 6 months), a normal gait pattern while wearing these walkers should be an important consideration.

This study compared the gait pattern in normal individuals wearing four commercially available short-leg walkers and a synthetic walking cast to determine which orthosis allowed the individual to simulate the most normal gait pattern.

MATERIALS AND METHODS

Patient Population. Six men and four women, with a mean age of 27.2±3.6 years, mean height of 171.9±10.4 cm, and a mean weight of 74.7±13.9 kg, were recruited for this study. Subjects were included only if they had no prior history of lower extremity injuries or surgeries. All subjects gave informed consent prior to participation in the study.

Subjects wore shorts and a T-shirt to allow for maximum exposure of their legs and pelvic area during testing. Only one side was tested for each subject. The side to be tested was randomly chosen just prior to testing.

Gait Measurements. Kinematic parameters were collected using a 5-camera Motion Analysis System (Motion Analysis Corporation Inc, Santa Rosa, Calif) that recorded at 60 Hz. Ground reaction forces were collected with an AMTI OR6-5 force platform (Advanced Medical Technology, Inc, Newton, Mass) embedded in the center of an 8-m walkway and recorded at 1000 Hz.

Inverse dynamics were used to derive kinetic information from the kinematic and ground reaction force data. Reflective markers were secured to anatomical locations with adhesive tape using the Helen Hayes Marker configuration.[4] Markers were placed bilaterally over the anterosuperior iliac spine, lateral knee epicondyle, lateral malleolus, directly on the shoe or walking boot over the head of the third metatarsal, and the posterior portion of the heel at the same level as the marker over the third metatarsal head.

Short 9.5-cm and 6.5-cm wands, with markers attached to the ends, were secured laterally to the mid-thigh and mid-shank regions, respectively, in line with the greater trochanter and lateral knee epicondyle marker for the thigh wand, and in line with the lateral knee epicondyle and lateral malleolus markers for the shank wand. A single marker was placed over the space between L5 ans S1 to identify the movement of the pelvis, in conjunction with the two anterosuperior iliac spine markers.

Each marker location was identified carefully with a surgical pen after attachment, to keep the locations of the markers fixed between the various conditions to eliminate errors with marker placement. Subjects were instructed to wear soft-soled shoes with a medium heel height on the day of testing. The mean heel height for the group test was 1.91±0.29 cm. The first condition tested was with the subjects' own shoes and was considered the "normal" baseline pattern against which the remaining conditions were compared.

Description of the Short-Leg Walkers. Four commercially available short-leg walkers and a synthetic short-leg walking cast were tested. The short-leg walkers were the:

- Bledsoe Walking Boot (Bledsoe Brace System, Inc, Grand Prairie, Tx),
- Three-D Orthopedic Samson (DeRoyal, Powell, Tn),
- Royce Equalizer (Royce Medical/Center Orthopaedics, Camarillo, Ca), and
- Cam Walker (Zinco Industries Inc, Pasadena, Ca).

The Bledsoe Walking Boot retails for about $50 and is constructed of lightweight aluminum with side arms. The boot has a heel height of approximately 1.9 cm, with about 1.5 cm of that comprising a soft rubber sole. The sole of this boot has a rockershaped bottom to approximate the three rocker motions of the ankle during gait. The sole is narrower at the heel (5.4 cm) and progressively expands toward the toes (8.9 cm). According to the manufacturer's literature, The Bledsoe Walking Boot is designed as a cast replacement for bracing fractures from the middle of the tibia or fibula to the mid-foot, and for second- and third- degree ankle sprains.

The Three-D Orthopedic Samson retails for approximately $45 and consists of an injected, molded plastic shell with fixed plastic arms as part of the midsole. This boot has wide medial/lateral paddles toward the upper calf portion. Heel height is approximately 3.8 cm, with about 6 mm of that comprising a hard rubber sole. The Samson boot has a relatively flat bottom sole with a figure-eight shape. The heel is approximately 8.6 cm wide, the middle section is approximately 7 cm wide, and the toe is approximately 8.9 cm wide. According to the manufacturer's literature, the Three-D Samson Boot is indicated for stable ankle and foot fractures, severe ankle sprains, and postoperative open reduction internal fixation.

The Royce Equalizer retails for about $55 and consists of injected, molded, glass-filled plastic, with plastic arms bonded to the shell. This boot has a wide foot plate (12.7 cm) that is nearly uniform throughout the entire sole. The heel height of this boot is approximately 4.2 cm, with a 3-mm hard rubber sole and a curved bottom sole. According to the manufacturer's literature, the Royce Equalizer Walker is indicated for soft-tissue injuries (grade 2 and 3 sprains), stable fractures, and postoperative use.

The Cam Walker retails for approximately $72 and consists of an injected, molded plastic shell with twin steel uprights and two hex screw adjusters for range of motion. This boot has a 5.4-cm heel height with a 3-mm hard rubber sole. The Cam Walker boot has a curved bottom sole with a figure-eight shape. The heel is approximately 7.9 cm wide, the middle is approximately 7.6 cm wide, and the toe is approximately 9.2 cm wide. The manufacture's literature for Cam Walker does not include indications for the boot.

Small, medium, and large sizes for each walker were available to accommodate all subject sizes. The synthetic walking cast used was Delta-Lite Casting Tape (Johnson & Johnson Orthopedics) and was applied by the same certified orthotist. A simple cast shoe was used in conjunction with the synthetic cast during testing.

Subject testing. The testing sequence for the walkers and cast was randomized. At the start of each condition, the randomly selected walker or cast was placed onto the subject's randomly selected limb by the same experienced kinesiologist or orthotist. Care was taken not to disturb the markers between conditions. Only the markers on the tested leg below the knee needed to be moved from condition-to-condition.

After application of the walker or cast, the lateral malleolus marker was replaced as close as possible over the location of the ankle malleolus. The shank wand was placed over the walker or cast, in line with the lateral knee epicondyle and lateral malleolus markers. The markers on the foot were placed as close as possible over the anatomical locations, but the foot markers were not critical since the walkers and cast constrained the ankle in neutral; therefore, the kinematic variables about the dorsiflexion/plantarflexion axis were not subsequently important.

After the walker or cast and markers were placed on the subject, the subject walked for several minutes to get accustomed to that particular orthosis. Once the subject was ready to proceed with the orthosis, five trials for that condition were recorded for averaging and further statistical analysis. Subjects were allowed to select their own walking speed and were allowed to rest when they felt the need.

Temporal-spatial parameters included calculations of velocity, cadence, and stride length. The kinematic parameters measured for the pelvis included obliquity, anteroposterior tilt, and internal/external rotation. For the hip and knee, flexion/extension and abduction/adduction kinematics were measured. Foot progression angle was the only parameter measured at the ankle, since the walking boots and synthetic cast locked the ankle at neutral in the dorsiflexion/plantarflexion and inversion/eversion planes. External moments were computed for the hip and knee about the flexion/extension and abduction/adduction planes.

Statistical Analysis. Difference curves were computed for all kinematic and kinetic parameters. Difference curves were calculated by subtracting the mean of the baseline shoe trial from the mean of each boot and cast condition for each subject. Therefore, the difference curves for each parameter for all 10 subjects represented a normalized effect of that particular walking boot or cast with respect to the baseline shoe trial.

A statistical technique called boot-strapping[5] was then used to computer the mean ans 95% confidence limits of the difference curves for the group for each parameter. When the upper or lower 95% confidence limit for a particular parameter crossed the zero line during the gait cycle, that portion was considered statistically significant. Temporal-spatial parameters were analyzed using the Mann-Whitney test at alpha=.05.

RESULTS

Temporal-Spatial Parameters. Temporal-spatial parameters are summarized in the Table. The synthetic cast was the only orthosis that demonstrated a significant reduction in velocity and cadence compared with the baseline shoe trials ($P<.05$). Stride length was not significantly different for all tested conditions and the baseline shoe trials.

Pelvic Kinematics. Pelvic kinematics during gait were virtually unchanged with the synthetic walking cast. Mean angular differences between the cast trials and the baseline shoe trials ranged from 1.3 to –1.2 for obliquity, 3.3 to –0.9 for anterior tilt, and 1.3 to –2.8° for internal rotation.

Pelvic kinematics also were close to baseline for all walking boots tested, with the exception of the Three-D Orthopedic Samson boot, which demonstrated a slight increased anterior pelvic tilt between 53% and 56% of the gait cycle, just before swing phase. Overall, the mean angular differences between the walking boots and the baseline shoe trials ranged from 1.5 to –1.2 for obliquity, 2.6 to –0.4 for anterior tilt, and 3.1 to –2.2 for internal rotation.

Hip Kinematics. Hip kinematics were not significantly different for the cast or any of the walking boots compared with the baseline shoe trials ranged from 1.9 to –2.6 for abduction and 5 to –1.8 for flexion.

Knee Kinematics. Knee flexion was significantly reduced during the cast trials compared with the baseline shoe trials for most of the stance phase (13% to 52% of gait cycle). Knee abduction/adduction kinematics were unchanged for the cast trials, and neither flexion nor adduction kinematics were altered by any walking boot. Average angular differences for the four walking boots compared with the baseline shoe trials ranged from 1.2 to –3.2 for adduction and 6.2 to –8.4 for flexion.

Foot Progression Angle. Foot progression angle was not significantly different in the cast or any walking boot compared with the baseline shoe trials. Average angular differences for the cast and four walking boots compared with the baseline shore trials ranged from 11.1 to –7.1 for internal rotation. All five orthosis demonstrated decreased external rotation during stance phase with an increased external rotation just after toe off into swing phase; however, no changes were statistically significant.

Hip Moments. Flexion/extension moments about the hip were not significantly different for the cast or any of the walking boots compared with the baseline shoe trials. However, the cast ana all of the walking boots, except the Bledsoe Brace, had statistically significant differences in the hip abduction moment compared to the shoe trials. With the cast, the external abduction moment was reduced during 15% to 19.2% of the gait cycle. The Three-D Orthopedic, Cam Walker, and Royce Equalizer boots demonstrated decreases in the external hip abduction moment during 38.4% to 41.4%, 12.6% to 16.8%, and 32.4% to 39.6% of the gait cycle, respectively.

Knee Moments. External knee adduction moments were significantly changed for the cast, the Three-D Orthopedics Samson, and the Cam Walker from 10.8% to 19.8%, 32.4% to 45.6% and 6% to 13.2% of the gait cycle, respectively. The typical knee flexion moment during stance phase was significantly reduced while in the cast from 9% to 33.6% of the gait cycle. The Cam Walker and Royce Equalizer also demonstrated some small but significant increases inn the external flexion moment during stance compared to the baseline shoe trials. The Cam Walker was significant between 25.8% and 35.4% of the gait cycle, and the Royce Equalizer was significant between 23.4% and 32.4% of the gait cycle.

DISCUSSION

The synthetic walking cast was the only orthosis that significantly altered gait from the baseline shoe trials. All of the walking boots performed better than the cast in allowing subjects to more closely simulate their baseline shoe gait patterns. The Bledsoe Boot performed the best, demonstrating no significant differences in any of the kinematic or kinetic parameters with respect to the baseline shoe trials.

Knee kinematics differences for all of the walking boots were insignificant for both the flexion/extension and abduction/adduction planes. Similarly, foot progression angle was not altered in either the walking cast or any of the walking boots during the gait cycle. The trend of the foot progression angle for all orthoses was a slight decrease in external rotation during stance and an increase in external rotation during swing.

The external moments about the hip also were not significantly different for any of the orthoses in the flexion/extension plane. However, in the abduction/adduction plane, the cast abs all of the walking boots except the Bledsoe boot had significant differences compared with the baseline shoe trials. These differences occurred during the higher loading portions of the stance phase. This alteration could lead to some abnormal joint loading that eventually may adversely affect the articular surfaces at the hip.

These differences probably can be attributed to the sole design of the boots. Structurally, all of the boots are basically the same, with a padded foot shell and semi-rigid side arms running up the shank. The biggest difference between the boots is the sole design and thickness. Since the kinetics at the hip are calculated after the knee joint kinetics, it was not surprising to see these differences when the external adduction moments about the knee were significantly affected in two of the four boots.

The external adduction moment about the knee was significantly reduced for the synthetic cast, the Three-D Orthopedic Samson, and the Cam Walker during a small portion of the stance phase. The external adduction moment at the knee is crucial for maintaining appropriate loads on the medial and lateral compartments of the knee, and is partly a result of the knee adduction/abduction angulation and the ground reaction component in the frontal plane.

These differences were not attributed to the knee adduction/abduction angulation, as that parameter was nearly identical for all boots. Therefore, the changes must arise from the ground reaction forces, which the authors believe is a direct result of the differences in the sole design. The Three-D Orthopedic and Cam Walker both have a figure-eight design with a thin hard rubber sole. The rigidity of the sole in these two boots limits the amount of mediolateral deviation from the inherent contour of the boots. The Royce Equalizer has a wide sole plate possibly controlling mediolateral play, and the Bledsoe Walking Boot with its soft rubber sole, allows for a natural positioning of the foot during stance.

For external flexion/extension moments, apart from the synthetic cast, the Cam Walker and Royce Equalizer demonstrated increased flexion moments about the knee during the muscle portion of the stance phase. This increase in the external flexion moment would require greater effort from the knee extensors and probably lead to higher than normal forces at the tibiofemoral and patellofemoral joints, and also slightly increase the physical demand of ambulation. Again, these differences probably can attribute to sole design.

The Cam Walker and Royce Equalizer both have a curved sole design, but with a thin, hard rubber sole. The sole design during mid-stance may not position the lower limb in the same manner as the natural ankle. This tends to increase the knee flexion angle and possibly increase the posterior ground reaction force, which both contribute to the increase in the external knee flexion moment. The Three-D Orthopedic Samson boot has a relatively flat sole, thereby allowing the lower shank to stay perpendicular during mid-stance. The Bledsoe Walking Boot has a three rocker sole design and a soft rubber sole that allows the shank to orient itself more naturally during stance. In addition, of the four walking boots, the Bledsoe Walking Boot has the lowest profile heel that most closely matches the heel height of a walking shoe, which also could be a factor in allowing the wearer to simulate a more normal gait pattern in that particular boot.

CONCLUSION

Walking boots offer several advantages over a synthetic walking cast. First, walking boots can be removed easily to allow range-of-motion exercises and direct visualization of the injured area. Second, the cost of these walking boots have reached levels well below their synthetic cast counterpart. Third, walking boots allow both the injured limb and the boot to be cleaned when necessary. Finally, as demonstrated in this study, walking boots have a less adverse effect on kinematic and kinetic gait patterns than a synthetic walking cast.

EDITORIAL DISCUSSION

ORTHOPEDICS: Normal subjects were tested in this study. However, the boots are applied only to patients. How do data from normal subjects carry over to patients, who will not have normal gait patterns to begin with?

Pollo et al: These boots are intended for patients who have foot and ankle problems. The purpose of a walking boot is to keep the foot and ankle in a relatively neutral position during ambulation with good support to distribute the load over a greater area. The gait parameters measured in this study were focused more at proximal joints (ie the knee, hip, and pelvis) and the effects that walking boots have on those areas. Therefore, these data do carry over to patients since ankle motion is eliminated in the boots and compensations must then be made at the proximal joints to ambulate.

Pain is the only factor that may become an issue, since if there is some pain or discomfort present while walking in these boots, then other compensations may be made by the patient to reduce the load and subsequent pain on the foot/ankle. This issue is beyond the scope of this study as we did not investigate the pressures or loads on the foot/ankle with each boot to determine which boot minimizes these factors during walking. The authors assumed that patients who use these boots will have normal knee and hip function without any significant pain while walking.

The boots serve the purpose of immobilizing the limb while making skin care and rehabilitation easier. Because these boots can be worn for long periods of time, their effects on gait patterns at other joints can become an important issue.

ORTHOPEDICS: Would the effects sometimes be more favorable and other times less favorable depending on the disability, surgery, and treatment of each patient category?

Pollo et al: The effects should always be favorable for any foot or ankle condition for which a walking boot is prescribed. However, we have not investigated the effect of pain in these boots and how that affects ambulation in these various boots. If there is severe pain while walking in the se boots, then it should be managed by analgesics or with nonweight bearing, and whether ambulation is normal in these boots is probably not of concern. Therefore, these data show that any foot or ankle condition that is not accompanied by pain would benefit from a walking boot that allowed a more normal gait pattern. Other factors that also could come into play but were not addressed in this study include other neurologic or musculoskeletal problems that could cause gait adaptations that may or may not benefit from a walking boot that allowed a more normal gait pattern in a healthy individual.

ORTHOPEDICS: The differences between the Bledsoe Boot and the other walking boots were minor. Can you comment on the differences that made the Bledsoe Boot perform slightly better than the other walking boots?

Pollo et al: The main difference between the Bledsoe Walking Boot and the other walking boots tested was the sole, design. The Bledsoe Walking Boot was the only boot with a three-part rocker design that mimics the natural ankle movement during the gait. In addition, The Bledsoe Walking Boot uses a thick soft rubber sole, providing more cushioning at heel strike and better transition through stance phase and toe-off, which is typically achieved through the ankle joint but has been lost as a result of the fixed ankle joint position.

Although these differences are minor, slight deviations from normal can lead to abnormal joint loading and increased physical demand. Therefore, is an individual has pain ata the knee or hip, or is in poor physical condition, one would prefer not to increase the loads across those painful joints or increase one's physical demand for walking.

TABLE
Temporal-spatial parameters

Orthosis	Velocity(cm/sec)	Cadence(steps/min)	Stride Length(cm)
Shoe	135.6 ±11.3	111.4 ±8.2	146.1 ±9.9
Synthetic cast	119.2 ±16.5	101.2 ±7.7*	141.9 ±11.6
Bledsoe	129.5 ±16.5*	107.4 ±7.1	146.0 ±7.9
Three-D Samson	132.1 ±14.8	107.1 ±8.1	147.9 ±8.8
Cam Walker	133.2 ±16.0	107.4 ±7.8	148.6 ±8.2
Royce Equalizer	131.0 ±14.9	106.1 ±7.3	149.1 ±8.4

**Significant difference compared with shoe condition, P<.05.*

REFERENCES

1. Polakoff DR, Pearce SM, Grogan DP, Burkhead WZ. The orthotic treatment of stable ankle fractures. Orthopedics. 1984; 1712-1715.

2. Birke JA, Nawoczenski DA. Orthopedic walkers: effect on plantar pressures. Clinical Prosthetics and Orthotics. 1988; 12:74-80.

3. Lavery LA, Vela SA, Lavery DC, Quebedeaux TL. Reducing dynamic foot pressures in high risk diabetic subjects with foot ulcerations. A comparison of treatments. Diabetics Care. 1996; 19:818-821.

4. Kadaba MP, Ramakrishnan HK, Wootten ME. Measurement of lower extremity kinematics during level walking. J Orthop Res. 1990; 8:383-392.

5. Olshen R, Biden E, Wyatt M, Sutherland D. Gait analysis and the bootstrap. Annals of Statistics. 1989; 17:1419-1440.