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Plantar pressures with total contact casting

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Abstract—Total contact casting has been used to aid in the healing of plantar neurotrophic ulcerations. The efficacy of total contact casts in promoting ulcer healing is presumably due to a reduction in the load over high pressure areas with pressure redistribution over the entire surface of the foot. The purpose of this study was to quantify the effectiveness of total contact casting in reducing plantar pressures. A portable microprocessor-based data-acquisition system was used for recording plantar pressures. Plantar pressures were collected from six nondisabled individuals with and without total contact casting at cast-walking cadence. In our study, there was a decrease in plantar loading under the metatarsal heads (first, fourth, fifth), the great toe, and the heel. The average decrease was 32% under the fifth metatarsal, 63% under the fourth metatarsal, 69% under the first metatarsal, 65% under the great toe, and 45% under the heel. Our study quantitatively showed that total contact casting does reduce vertical plantar pressures in high load areas.

Key words: *casts, diabetic neuropathies, gait, plantar pressure.*

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INTRODUCTION

Total contact casts have been used for decades to promote healing of plantar ulcerations secondary to neuropathy. This technique was originally described in the 1930s by Dr. Joseph Kahn in patients with Hansen's disease (1). Dr. Paul Brand expanded the application of total contact casting to neuropathic ulceration in diabetes mellitus which has been pursued by Dr. Helm and her colleagues (2–4). Total contact casting has been used not only in diabetic neuropathies but also in plantar ulcerations due to alcoholic neuropathy, syringomyelia, tabes dorsalis, yaws, spina bifida, and Charcot-Marie-Tooth disease (5,6). Dr. Myerson and associates demonstrated that the total contact cast provided safe, reliable, and cost-effective treatment for neuropathic ulcers of the foot (7).

The efficacy of total contact casts in promoting ulcer healing is presumably due to reduction of the load over high pressure areas via pressure redistribution over the entire surface of the foot. This concept has not been proven, however. Kominsky hypothesized that there may be two additional factors contributing to plantar unloading (8). First, the total contact cast forces the patient to shorten the stride length and the walking velocity is decreased which diminishes the vertical forces on the foot. Second, the cast eliminates the motion at the ankle joint in the sagittal plane, which in turn decreases the propulsive phase of the gait cycle. Certainly, the most direct effect that the total contact cast has on the foot is its ability to increase the plantar surface area.

Although total contact casts have been used for decades, only limited studies have been done to quantify changes in plantar pressures. Dr. Dorey studied the effect of a short leg walking cast on the pressures between the cast and leg/foot in the static stance phase by a pneumatic pressure device (9). He found that the walking cast did spread out the weight across the arch and at the edges of the foot. Birke and colleagues investigated plantar pressures inside total contact walking casts for 36 steps using discrete pressure transducers at four sites on the plantar surface: first, third, and fifth metatarsal heads and the heel. They found a relative decrease in plantar pressures over the first and third metatarsal heads (10). Since an oscillographic recorder was used for their study, relative plantar pressures were reported in mm chart deflection instead of absolute pressure values. The purpose of this study was to quantify the changes in plantar pressures over an extended period of continuous cast walking.

METHODS

System Description

The data collection system consisted of eight resistive pressure transducers of 0.5 mm thickness and 11 mm diameter (Interlink Electronics, Santa Barbara, CA 93105) connected to a lightweight microprocessor-based portable pressure recording module carried by the subject in a backpack (11). Transducers were backed by a rigid metal plate to prevent bending artifact and dynamically calibrated with a load cell as the reference. Eight transducers were securely taped over the first, second, fourth, and fifth metatarsal heads, medial and lateral midfoot, calcaneal midline, and plantar aspect of the great toe of the left foot. These positions are common sites of plantar ulceration (12) and have easily palpated anatomical landmarks for consistent application. Consistent transducer location during data collection was assured by inspection of the foot before and after every stage of data collection. The system is capable of continuously sampling 14 channels of pressure data for 7 min at a 35-Hz sample rate. The recorded data are downloaded into a microcomputer through a parallel interface for data processing, analysis, and display.

Subjects

Six males (physicians, residents, and engineers) ranging in age from 25 to 40 years were studied. All subjects were free of gait abnormalities, lower extremity deformaties, edema, ulcers, and vascular disease. All subjects had normal plantar sensation as determined by a threshold Semmes-Weinstein monofilament test (13). This project was approved by the hospital's Human Subject Review Board.

Casting Technique

A total contact cast was applied according to the protocol described by Coleman et al. (14), modified by the application of a fiberglass reinforced outer shell for early weightbearing. The cast was applied with the subject in the prone position on the casting table with the knee flexed at 90°, the ankle joint in pronation and at 90°, and the forefoot in the neutral position. Foam padding (Reston™, 3M Medical-Surgical Division, St. Paul, MN 55144) was applied and placed over the toes to prevent interdigital maceration. A standard stockinette tube was used to cover the foot and leg and carefully trimmed to avoid folds. Both malleoli were covered with disks of 1/4-inch (0.625 cm) orthopedic felt (Zimmer Inc, Warsaw, IN 46580) fixed with paper casting tape. An anterior strip of 1/4-inch (0.625 cm) orthopedic felt was placed over the tibial crest and dorsum of foot. One roll of fast setting plaster (Specialist™, Johnson & Johnson Products, New Brunswick, NJ 08903) was applied, carefully rubbed into all contours of the foot and leg, and allowed to set. Another roll of plaster was applied with five layers of splinting over the plantar surface and toe areas. A 1/4-inch (0.625 cm) plywood board was placed over the plantar surface of the cast. This board extended from the metatarsal heads to mid-heel with the arch of the foot between the plaster layer and plywood board carefully filled in with plaster. A rubber walking heel (Zimmer Inc, Warsaw, IN 46580) was placed at approximately 40 percent of heel-to-toe distance. Two additional 4 in × 4 yd (1.25 cm x 3.66 m) rolls of fiberglass casting material (Zim-Flex™, Zimmer Inc.) were applied for extra strength and early weightbearing.

Test Protocol

Subjects wore extra depth shoes (PW Minor, Batavia, NY 14020) at all times during data collection except when casted. For each test, the subject walked a total of 720 m (6 laps of 30 m/lap × 4). A total of four sets of plantar pressure data was taken per subject. First, the subject walked at a spontaneous self-selected cadence. After this initial trial a total contact cast was applied. Weightbearing was not allowed for 3 to 4 hrs setting time to assure sufficient hardening of the plaster inner shell. The subject then walked the course with the total contact cast at a comfortable self-selected cadence. After cast removal, data were obtained at the casted cadence with pacing from a metronome. Final data were taken at the initial uncasted cadence, again with pacing via metronome. Pressure data were sampled at a rate of 35 samples per sec.

Table 1.
Peak plantar pressures (kPa) during cast and normal walking.

Sensor Locations	Normal Walking	Cast Walking
Heel	1020 (±761)	905 (±673)
Lateral midfoot	262 (±186)	224 (±95)
Medial midfoot	115 (±180)	101 (±54)
5th metatarsal	273 (±56)	179 (±24)
4th metatarsal	440 (±185)	160 (±69)
1st metatarsal	602 (±280)	286 (±281)
Hallux	1082 (±566)	333 (±294)

*kPa = kilopascals (10^3 N/m^2).
Normal walking is at casted cadence.

Data Analysis

Pressure data were collected over four laps of a 30 m course during straight line, steady state walking only. Effects of acceleration and deceleration within 5 m of turnaround points were controlled by rejecting data collected during these periods. Data were taken using the distances and acclimatization as used by Zhu et al. (11) previously. Excluded data included 5 m of deceleration and acceleration at the end points of the course correlated with the timing recorded on a stopwatch separate of the machine. Raw data were inspected for obvious errors. Peak plantar pressures were processed from raw pressure-time data. Data were compiled and analyzed using the student's T-test ($p = 0.05$). Data comparison included analysis of peak pressures at each of the pressure points both with and without the total contact cast at a cast walking cadence. Statistical significance of the pressure differences between total contact cast and non-total contact cast walking was calculated.

RESULTS

Table 1 shows the average peak plantar pressures during both walking with total contact cast and normal walking at casting cadences under the heel; lateral and medial midfoot; first, fourth, and fifth metatarsals; and great toe of the left foot. The range of peak pressures are from 115 kPa to 1082 kPa for normal walking and from 101 kPa to 905 kPa for cast walking. Intersubject standard variations were also shown in the table. Data from the second metatarsal head were rejected because of failure of the sensor connectors.

Table 2 shows the percentage differences between cast walking and normal walking at cast cadence. There was an average decrease of 32.2 percent (4.7–48.2 percent) in plantar pressures under the fifth metatarsal in all subjects when walking with the cast. There was an average decrease of 63.2 percent (53.5–69.8 percent) in plantar pressures under the fourth metatarsal in all subjects when walking with the cast. There was an average decrease of 65.3 percent (6.5–87.4 percent) in plantar pressures under the great toe in all subjects when walking with the cast. In 5/6 of the subjects, the first metatarsal was unloaded by an average of 68.6 percent (37.8–84 percent). In 4/6 of the subjects, the heel was unloaded by an average of 44.5 percent. In half of the subjects, there was an increase in loading under lateral midfoot with the cast; in the other half, there was a decrease in lateral midfoot loading. In 4/6 of the subjects, the medial midfoot was not loaded during normal walking, but was loaded 59–195 kPa when walking with the total contact cast. The other two subjects did have medial midfoot loading (296–392 kPa) during normal walking. Interestingly, these two subjects showed a decrease in midfoot loading (50–117 kPa) with the cast.

DISCUSSION

Dr. Paul Brand has hypothesized that a difference between the sensate and insensate gait is that

Table 2.
Differences in plantar pressures during cast walking and normal walking (%).

Subjects	Heel	L midfoot	M midfoot	Sensor locations 5th meta.	4th meta.	1st meta.	Hallux
1	− 70.6	+ 47.0		− 48.2	− 53.5	+ 12.8	− 81.9
2	− 5.4	− 48.1	− 83.1	− 34.4	− 69.8	− 81.5	− 6.5
3	+ 681.3	− 0.8	− 70.2	− 47.1	− 63.1	− 37.8	− 76.3
4	− 81.9	− 37.9		− 4.7	− 66.3	− 84.0	− 87.4
5	− 19.9	+ 30.7		− 23.0	− 62.0	− 79.3	− 54.8
6	+ 34.6	+ 122.1		− 36.0	− 64.3	− 60.4	− 84.6

Normal walking is at casted cadence.

over time the sensate will begin to limp to avoid repetitious overloading of a section of the foot (2). The insensate do not get sufficient sensory feedback from the foot and thus do not develop this protective limp. Thus, the insensate can excessively load areas repetitively with resultant tissue damage. Many investigators have shown that diabetic patients produce high pressures over areas of plantar ulceration (15–19). It has been suggested that neurotrophic foot lesions may be due to the lack of this adaptive, protective limp.

Short leg walking total contact casts have been advocated by Brand and Coleman for plantar ulcerations on insensitive feet (14). Dr. Phala Helm et al. studied their clinical efficacy and found that 72.7 percent of their diabetic patients showed healing of their neuropathic ulcerations in an average of 38.3 days (3). Other studies have shown total contact casting resulting in mean healing times ranging from 37.8 to 43.6 days (20–22). Helm et al. also studied the recurrence of neuropathic ulceration following healing in a total contact cast in a 6-year prospective study (4). The main reasons for ulcer recurrence were patient compliance, persistent destructive plantar pressures, unvaried walking patterns, and osteomyelitis. Total contact walking casts have the advantage of increased patient compliance (86.4 percent) over other treatments such as frequent dressing changes, bed rest, and hospitalization (3). Other methods used to treat plantar ulcerations report longer healing times. Molded insoles were reported by Holstein et al. to have a mean healing time of 3.6 months (23). Mueller et al. have shown traditional dressing techniques to have a mean healing time of 65 days (21). The Scotchcast below-ankle boot with pre-cut windows over ulcer sites has a mean healing time of 3 months, and also has other disadvantages including window edema, and potential damage to healthy tissue surrounding ulcer sites if windows are not trimmed properly (24). Contact casts cost less than dressing supplies over the normal course of treatment, minimize income loss due to inability to work, and minimize interference in activities of daily life. Since casting is an outpatient treatment, use of this technique also reduces hospitalization costs.

Studies by Soames and Zhu et al. have shown an effect of cadence on ground reaction forces (25–27). Soames discovered a positive correlation between increasing cadence and vertical ground reaction force. Since most subjects walk at a slower cadence when wearing the cast, it is important to quantify the contribution of slowed cadence to pressure reduction. To eliminate this effect of cadence on plantar pressures, we used the freely chosen cast cadence for both cast walking and non-cast walking.

The efficacy of total contact casts in promoting ulcer healing is presumably due to a reduction of the load over high pressure areas with pressure redistribution over the entire surface of the foot. In our study, there was a decrease in plantar loading under the metatarsal heads (first, fourth, fifth), the great toe, and the heel. The average decrease was 32 percent under the fifth metatarsal, 63 percent under the fourth metatarsal, 69 percent under the first metatarsal, 65 percent under the the great toe, and 45 percent under the the heel. Our study quantitatively showed that total contact casting does reduce vertical plantar pressures. Shear forces may also play a significant role in plantar ulceration. The effect of total contact casting on plantar shear stress is unknown. Further studies are in progress to determine the effects of total contact casting on plantar shear stress.

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