

Adaptive gait responses to plantar heel pain

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Abstract—Neuropathic foot ulcers in people with diabetes result from repetitive stress aggravated by a lack of protective sensation. Protective sensation causes individuals without this impairment to produce alterations in their gait in response to painful stimuli. This study evaluates the adaptive gait responses to pain in individuals with sensate feet. The gaits of 18 such control subjects were studied with a foot switch gait analyzer without painful stimuli. Each then had his or her gait analyzed with three successively larger painful stimuli (2, 3.3, and 4.6 mm beads) placed below the heel. This study showed that subjects compensated for the painful stimuli by reducing the single limb support duration of the affected side at bead sizes of 3.3 and 4.6 mm and by reducing the unaffected side's swing phase and single limb support as a percentage of the gait cycle at the 4.6-mm bead size only. Gait adaptations to painful stimuli may indicate another possible avenue, in addition to pressure redistribution, in the assessment of programs aimed at prevention and treatment of diabetic foot ulcers.

Key words: *diabetes, insensate foot, gait, plantar ulcer.*

INTRODUCTION

Studies have consistently shown that pain alters gait. Gait disturbances can be used in the evaluation of chronic low back pain and subject response to spinal arthrodesis (1). Gait analysis and reports of pain correlate well in persons before and after knee replacement (2,3).

However, there is a paucity of data regarding specific gait changes in nonimpaired subjects as a response to painful stimuli. Pain producing a limp clearly changes gait. Information as to the magnitude of stimulus required to produce a limp or gait change, or perhaps more importantly, the amount of pain perceived by the subject, is unavailable. Difficulty in quantifying pain or its perception is one of the major reasons for the limited number of studies (4,5). The use of the visual analogue scale, however, has been shown to be a reliable assessment of pain magnitude (1).

The relationship between pain and gait alteration secondary to pain has specific clinical relevance to persons with reduced protective sensation. Such individuals are prone to develop ulcers on their feet from repetitive weight-bearing pressure, resulting in significant morbidity and economic loss. Worldwide, Hansen's disease is a major cause of loss of protective sensation and neuropathic ulcer formation (6), while diabetes mellitus is the primary cause in the United States (7). Identification of characteristic adaptive gait patterns resulting from painful stimuli to the foot in subjects with sensate feet could provide a means of assessing interventions aimed at reducing contact pressures in persons with reduced protective sensation. Treatment of pressure-related ulceration focuses on elimination or redistribution of pressure. Total contact casting has been shown to reduce pressures on the foot up to 69 percent during normal cast walking cadence (8). Total contact casting may also reduce pressures by causing the subject to alter gait, specifically with a shortened stride length and reduced velocity (9).

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Ascertaining the protective gait responses of individuals with sensate feet and the pain thresholds at which the responses occur may illustrate the value of treatment modalities that not only reduce pressure but also compel the person to alter gait. This study was designed to test the hypothesis that pain correlates with gait changes and that adaptive responses in individuals with sensate feet would consist of a reduction in velocity, stride length, and single limb support duration.

METHODS

We recruited 18 individuals with sensate feet whose ages ranged from 21 to 45 years: 7 women (means: age=28.8, weight=76.2 kg) and 11 men (means: age=30.7, weight=65.3 kg). The study was performed at the UCI Medical Center in the orthopaedic and physical therapy clinics. All subjects signed the consent form of the UCI Committee for Human Research and were provided with a copy of the UCI Subject's Bill of Rights.

All subjects underwent a basic gait analysis conducted by one researcher using the VA-Rancho foot switch stride analyzer (B&L Engineering, Santa Fe Springs, CA) that employs innersole foot switches on a 10-m walkway with a photoelectric timer. Prior to the formal study, a number of runs were made with and without a 2.54-cm diameter flat plate, 1 mm thick, under the heel. No alterations in gait were noted, and no subjects reported pain or discomfort or any sensation of the plate. A total of three runs were made for each subject without a plate or bead. Subsequently three additional trials were performed with 2, 3.3, and 4.6-mm steel beads placed under the heel (**Figure 1**). Three separate runs were made with each size bead. The bead size during each run was not randomized, but done in increasing order of size, in order to minimize the effect of each preceding run on the next. Subjects all wore their own comfortable dress shoes, made of leather with solid hard rubber or leather heels of no more than 1.9 cm in height. These shoes were chosen so that a comfortable fit was assured and the shoes had been broken in. The use of single type and brand of shoe for each person would not have assured a comfortable fit and thereby potentially resulted in an alteration of gait secondary to the fit of the shoe and not from the controlled heel stimuli.

Each bead was fixed to a 2.54-cm diameter flat steel plate to provide a constant elevation of the bead

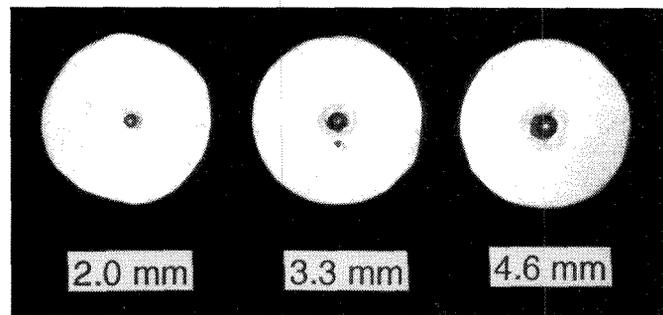


Figure 1.

Beads used in the study, mounted at the centers of 2.5-cm base plates.

from the inner sole of the shoe. The plate distributes the pressure from the bead on the sole of the shoe and minimizes the differences between the physical properties of each shoe. The beads were taped in place on the innersole foot switches 2.5 cm from the posterior of the right heel counter. These were then slightly adjusted to the point of maximal tenderness under the heel. Each subsequent bead was placed in the same position on the foot switch.

The following variables were recorded: velocity (m/min), cadence (steps/min), stride length (m), gait cycle (s), right and left values for single limb support (s), and for double stance (s).

Pain was evaluated using a visual analogue scale. This scale consists of a 10-cm horizontal line labeled with verbal anchors at either end: "no pain" on the left and "pain as bad as it could possibly be" on the right. The subjects were instructed to mark the horizontal line after each trial. These marks were then converted to numerical scores equal to the distance in cm from the left end of the scale. The data were analyzed by bead size with each person serving as his/her own control. The bead data were also divided into five groups by pain score without respect to bead size and compared to the control group. The following groups were analyzed: pain < 1, pain > 1 and < 2, > 2 and < 3, > 3 and < 4, > 4 and < 5, and > 5. These groups were also compared to the control group. The results were also evaluated based upon bead size compared to the no bead trial.

Statistics

All statistical comparisons were performed using a one-way ANOVA. Differences were considered significant at $P < 0.05$. ANOVA analysis of all variables was performed comparing variation across runs in each individual trial as well as across trials. Additionally, all

the data with painful stimuli were grouped by pain score and ANOVA analysis was performed evaluating the variation of the data from the control, based on pain groupings alone.

RESULTS

The data for each experimental condition are shown in **Table 1**. The velocity, cadence, and stride lengths of the control measurements were within one standard deviation of the data reported in the literature for nonimpaired adults (10). When comparing the bead trials to the control, the single limb support (SLS) and the SLS as a percentage of the total gait cycle (GC) of the right lower limb and the left swing phase expressed as a percentage of the total GC varied in a statistically significant way. The right SLS was 0.41 s in the control group and fell to 0.38 s ($P=0.001$) in the 4.6-mm bead trial. The right SLS in the 2-mm bead trial fell to 0.40 s and was statistically different from the 4.6-mm bead trial ($P=0.017$). Right SLS as a percentage of GC was 38.5 percent in the control group and fell to 36.9 percent ($P=0.012$) in the 4.6-mm bead trial. The other

bead sizes did not vary in a statistically significant way. Left swing phase as a percentage of GC was reduced from the control trial of 38.9 percent to 36.9 percent ($P=0.01$) in the 4.6-mm bead trial.

No other statistically significant difference was noted in other variables evaluated when comparing the bead trials to control trials and the bead trials among themselves. No statistically significant differences were noted between the three successive runs in each trial. Age, weight, and sex failed to yield any statistically significant differences.

Average pain scores for the 2, 3.3, and 4.6-mm bead trials were 0.46, 1.64, and 3.61 respectively. The control group was 0 by default. Pain scores versus bead sizes are plotted in **Figure 2**.

Cadence, GC, left and right swing phase as a percentage of the GC, left and right SLS, and left and right SLS as a percentage of the GC were found to be significant ($p<0.05$) but not across all pain level groupings. No statistical differences for any variable evaluated compared to control was found with a pain score less than 1, and only right SLS as a percentage of the GC was found to be significant at a pain score above 5.

Table 1.

Gait analysis results for control measurement and for 2.0, 3.3, and 4.6-mm bead trials. All data are derived from 18 subjects with three measurements for each gait condition.

	Controls		2.0-mm bead		3.3-mm bead		4.6-mm bead	
Velocity (m/min)	82.2	(8.8)	84.8	(10.6)	85.0	(10.1)	83.2	(9.6)
Cadence (step/min)	112.9	(7.0)	114.7	(7.5)	115.4	(7.4)	115.4	(7.3)
Stride Length (m)	1.45	(0.12)	1.48	(0.13)	1.47	(0.13)	1.44	(0.12)
Gait Cycle (sec)	1.07	(0.07)	1.05	(0.07)	1.04	(0.07)	1.04	(0.07)
SLS R (sec)	0.41	(0.03)	0.40	(0.03)	0.39	(0.04)	0.39	(0.04)
SLS R % Cycle (%)	38.5	(2.3)	38.2	(2.5)	37.5	(3.0)	37.1	(3.0)
SLS R % Swing (%)	39.1	(1.7)	38.7	(2.8)	38.9	(2.6)	39.3	(2.6)
SLS L (sec)	0.42	(0.02)	0.41	(0.03)	0.41	(0.03)	0.41	(0.03)
SLS L % cycle (%)	39.1	(1.7)	38.7	(2.8)	38.9	(2.6)	39.3	(2.6)
SLS L % swing (%)	38.9	(3.1)	38.2	(2.5)	37.5	(3.0)	37.1	(3.0)
DLS (% cycle)	22.3	(3.6)	23.1	(4.8)	23.7	(5.1)	23.8	(4.7)
Pain Score 1-10			0.5	(0.6)	1.7	(1.1)	3.6	(1.5)

SLS = single limb support; DLS = double limb support; m = meters; R = right; L = left; () = standard deviation.

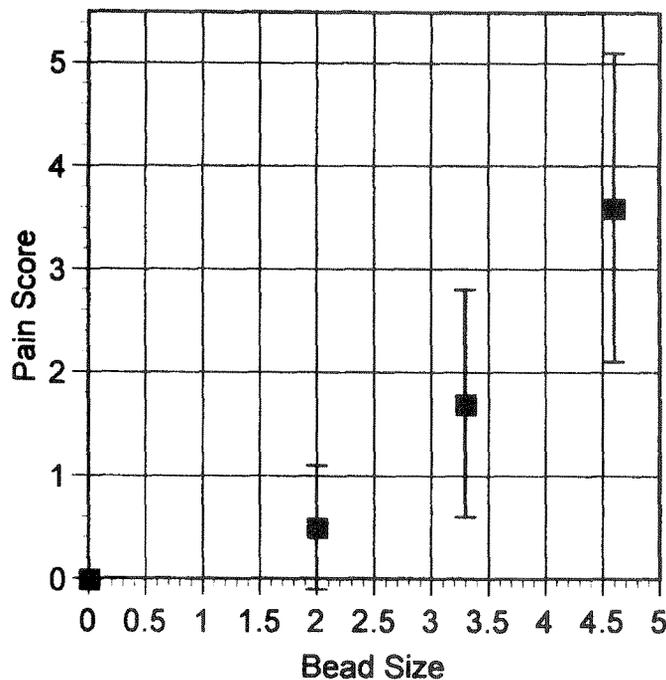


Figure 2.
Bead size versus pain score.

DISCUSSION

Evaluation of pain and its effect on gait is subject to multiple variables, including individual pain tolerance and anthropometric variables. Lack of randomization of the beads could result in a conscious or unconscious modification of subject gait. The data analysis attempts to evaluate these different variables by looking at the groups in terms of the size of the painful stimuli, the subject's perception of the stimuli, and evaluation of the effect of height, weight, and sex. Conscious or unconscious modification of a subject's gait in response to being in a study cannot be evaluated in the current setting. The foot contact patterns provided by the VA-Rancho foot switch stride analyzer were found not to provide useful information in this circumstance: changes in these were too subtle to be quantified and no meaningful information could be drawn from them.

Our hypothesis was that the response to increasing painful stimuli would result in a shorter SLS time on the affected side, a shorter double stance time, and a reduction in velocity. The significant compensatory responses in this study were a reduction in the SLS of the affected side at bead sizes of 3.3 mm and 4.6 mm, and a reduction in the unaffected swing phase and SLS

as a percentage of GC on the affected side in the 4.6-mm trial. This suggests that the critical size of defect in the heel needed to produce acute changes in gait lies between 2 and 3.3 mm. The initial response to pain in the heel is to reduce the SLS on the affected side with preservation of the GC length. As the magnitude of the stimulus increases, the GC and the contralateral swing phase decrease in an attempt to minimize exposure to the noxious stimulus. Velocity and stride length did not vary significantly when evaluated by bead size or when evaluated by pain score. Studies of total contact casting have demonstrated a reduction in contact pressures as well as a shortened stride length and reduced velocity (9). A total contact cast represents a significant impediment to normal gait as it also immobilizes the ankle. The small beads in our study represent only a small stimulus compared to a total contact cast and may not have been significant enough to result in a reduction in velocity and stride length. With increasing size of bead, it is likely that a reduction in both velocity and stride length would be observed.

Evaluation of the data on the basis of pain alone shows a number of statistically significant differences at all pain levels. These differences were not consistent from pain group to pain group. No correlation was found for any variable evaluated with a pain score less than 1, and only right SLS as percentage of GC was found to be significant at pain score above 5. Below a pain score of 1, it is likely that there is no demonstrable effect on gait parameters. The limited number of scores in the higher pain ranges were probably too few to provide statistical significance. The somewhat spotty correlation in the lower pain group may in part be due to the inherent subjectivity of the visual analogue scale and too few subjects to provide statistical significance. The right SLS was statistically significant at pain groups >2 and <4 . At higher pain groupings, there were fewer subjects and consequently no demonstrably significant difference from control. It appears that even a small perceived stimulus (pain >2) can result in an alteration of gait. This has been noted in adults with transtibial amputations, who modify their gait to minor alterations in their prostheses that they cannot otherwise detect (11). This may in part be an artifact in that the subjects knew they were participating in a study, and when a bead was placed in their shoe they modified their gait as a result of this knowledge. Subjects were unaware of the bead sizes but knew they were increasing in size with each new run.

As these were short-term tests, it could be expected that each bead would become more painful if walked on for the longer periods common to those with insensate feet. Gait adaptations to painful stimuli may indicate another possible avenue, in addition to pressure redistribution, in the assessment of programs aimed at prevention and treatment of diabetic foot ulcers.

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