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CLINICAL REPORT

The Relationship Between Gait Parameters and Pain in Persons with Transtibial Amputation: A Preliminary Report

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Abstract—This is a preliminary study of the potential relationship between pain and gait parameters in 11 persons with transtibial amputation who underwent gait analysis under both baseline and discomfort walking conditions. Gait analysis included measurement with a VA-Rancho Stride Analyzer of the following gait parameters: velocity, cadence, stride length, gait cycle, and support time. These data were correlated with pain intensity data determined with a standard Visual Analog Scale. Wide ranges of discomfort were reported and corresponding alterations in gait parameters varied greatly in both magnitude and quality. There was no obvious pattern in acclimation to discomfort. A significant correlation was found between pain intensity and the magnitude of change in velocity ($p<0.05$). In addition, all subjects reporting significant pain (>33% of maximum) slowed down, while gait alterations of others varied widely in response to the experience of pain. Further studies with a larger and more homogeneous subject pool to examine these relationships fully are recommended to follow this preliminary report.

Key words: *gait, pain, transtibial amputation, VA Rancho Stride Analyzer, Visual Analog Scale.*

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INTRODUCTION

Only a few studies (1–5) have investigated the relationship between pain and stride characteristics of gait. An early study of the relationship between clinical evaluation and gait parameters in persons having polycentric knee arthroplasty found significant correlations between pain and velocity as well as between pain and the difference in single-limb support (SLS) time (1). A later study corroborated these findings after investigating the relationship between pain intensity and improved stride characteristics before and after total knee arthroplasty (2). More recently, gait analysis has been found useful in assessing function in persons with chronic low back pain, and disability in gait was found to correlate strongly with lower back pain reported before and after spinal arthrodesis (3). Other studies have measured reactions to joint pain that may cause alterations in gait, such as deformity of the natural resting posture of swollen joints (6) and muscle weakness secondary to joint swelling (7). Pain as a limitation to mobility has been linked to cancer, arthritis, and postsurgical conditions as well (8–10).

It may seem obvious that pain would limit the gait performance of persons with transtibial amputation (TTAs), yet, of the numerous studies that have assessed walking ability of such subjects (11–19), none has investigated pain intensity as a variable in their walking performance. While this lack is due in part to the

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difficulties associated with reliably quantifying pain (20–23), the Visual Analogue Scale (VAS) has emerged in numerous independent studies as a valid and reliable measure of pain intensity (22–24).

Pain may severely limit TTAs from achieving more successful ambulation. For example, the jarring impulse created by the repetitive planting of the prosthesis is believed to register pain at the residual limb, and this pain is thought to be a rate-limiting factor in the gait (25,26). Aside from the obvious direct limitation that pain would impose on walking ability, the increased energy cost of strategies to avoid pain or discomfort (27,28) also must be considered as an obstacle to the improved gait of a person with pain during ambulation.

Significant correlation between pain and gait parameters could underscore the importance of adding more pain alleviation strategies to the rehabilitation of TTAs. Pain measurement may also prove to be a valuable tool for assessing gait function in these individuals. The objective of this research was to test the hypothesis that pain intensity reported by TTAs correlates positively with diminished velocity, decreased step length, and decreased SLS time. The research was intended to determine whether prosthetic pain is a primary factor in their gait impairment.

METHODS

Subjects

This study, conducted at the Rehabilitation Research and Development facility at the San Francisco VA Medical Center, evaluated a subject group of 11 TTAs recruited from the VA Medical Center prosthetics lab and from clients of the San Francisco Orthopedic Prosthesis Company from May 1993 until May 1994. Volunteers were contacted in accordance with the University of California at San Francisco committee for human research rules and consented to participation in the study. Descriptive data are presented in **Table 1.** The cause of amputation was trauma in eight cases and vascular insufficiency in three cases: **Table 2** lists the amputations and prostheses. All subjects participated in the baseline walking trials described in **Table 3,** but those with a fragile residual limb or significant prior pain were excluded from the pain production protocol as noted in **Table 4.**

Table 1.
Descriptive data for subjects with transtibial amputation by sex, age, and size.

Subject #	Sex	Age	Height	Mass
1	m	71	1.75	88
2	m	69	1.73	109
3	m	68	1.85	82
4	m	47	1.83	79
5	m	83	1.83	92
6	m	51	1.75	77
7	f	76	1.60	68
8	m	54	1.75	100
9	f	73	1.65	63
10	m	55	1.83	86
11	m	64	1.93	107
average		64.6	1.77	86.5
SD		10.9	0.09	14.2

Age in yrs; height in m; mass in kg; SD=standard deviation.

Gait Analysis

All subjects underwent basic gait analysis followed by evaluation of the pain experienced during the gait trial. Gait analysis included evaluation of velocity, cadence, stride length, and SLS and double-limb support (DLS) time (percent of gait cycle), and was conducted by one investigator using the VA-Rancho foot switch stride analyzer (B&L Engineering, Santa Fe Springs, CA) on a 10-m walkway with innersole foot switches and a photoelectric timer. Three runs were made for each prosthetic condition. SLS and DLS times were obtained by averaging the values for each leg for all runs of a given prosthesis condition. Standard statistical data and comparison to control data were obtained directly from the stride analyzer (29).

Pain Measurement

A standard Visual Analogue Scale was used in this study (20,21). It consists of a 10-cm horizontal line labeled with verbal anchors at either end. The left and right anchors read "no pain" and "pain as bad as it could possibly be," respectively. The subject was instructed to mark the scale according to the level of pain experienced after each walking trial, providing a numerical pain score for each trial equal to the distance in centimeters from the left end of the scale to the mark.

Pain Production

Each pain-free (PF) subject underwent temporary prosthesis modification to create a slight pressure at the anterior medial surface of the leg inferior to the

Table 2.
Subject data for prosthesis side, type of prosthesis, and reason for amputation.

Subject #	Side	Reason	Prosthesis type
1	l	trauma	PTS, soft liner, SAFE foot
2	r	trauma	PTS, soft liner, SAFE foot
3	r	trauma	PTB, soft liner, flex foot
4	l	vascular	PTB, soft liner, multi-axis foot
5	l	vascular	PTB, soft liner, SACH foot
6	r	trauma	PTS, soft liner, SAFE foot
7	l	trauma	PTS SAFE foot
8	l	trauma	PTB Flex foot
9	r	vascular	PTB, silicone liner, susp. sleeve, SACH foot
10	l	trauma	PTB, susp. sleeve, Seattle foot
11	r	trauma	PTB, silicone liner, susp. sleeve SAFE foot

PTS=Patellar Supracondylar; SACH=Solid Ankle, Cushion Heel; PTB=Patellar Tendon Bearing; SAFE=Stationary Attachment, Flexable Endoskeleton.

Table 3.
Results of average gait analysis and measurement of baseline pain intensity for the subjects with their own prostheses.

Subject #	Velocity	Cadence	Stride length	Gait cycle	SLS prosthetic	SLS sound	DLS prosthetic	DLS sound	Pain intensity
1	70.9	106	1.33	1.13	0.43	0.42	12.7	12.1	0
2	66.8	95	1.40	1.26	0.43	0.52	14.7	10.1	0
3	73.7	101	1.46	1.19	0.44	0.48	11.7	11.7	0
4	62.9	86	1.48	1.41	0.52	0.56	9.2	14.9	0
5	46.3	90	1.04	1.34	0.42	0.15	9.1	48.3	60.5
6	55.6	80	1.39	1.50	0.53	0.63	10.9	11.7	0
7	56.8	106	1.08	1.13	0.39	0.38	20.1	11.9	0
8	58.9	100	1.19	1.21	0.44	0.49	15.2	7.4	0
9	62.4	108	1.15	1.11	0.42	0.39	15.9	10.7	0
10	69.5	105	1.32	1.14	0.41	0.44	16.4	9.0	0
11	77.3	102	1.52	1.18	0.43	0.43	14.3	12.9	0
avg	63.7	98.1	1.3	1.23	0.44	0.44	13.7	14.6	
SD	9.0	9.2	0.17	0.13	0.04	0.12	3.3	11.3	

Velocity in m/min; cadence in steps/min; stride length in m; gait cycle=time between two initial sequential contacts by the same limb, in s; SLS=single limb support: time for total weight bearing on one leg, in s; DLS=double limb support: time for stance with both feet contacting the floor, as percentage of gait cycle; pain intensity as percentage of maximum; avg=average; SD=standard deviation.

tuberosity of the tibia, so that the individual reported mild discomfort, analogous to that of walking with a smooth flat pebble in one's shoe. To achieve this effect, between one and three smooth 1.5-cm diameter plastic disks approximately 2-mm thick were placed in the socket. The number of disks used depended on the individual, because the intent was to restrict the discomfort of each member in this group to a similarly mild level as indicated by subsequent report on the visual analogue scale. Participation in this protocol was restricted as follows: Subject #7 was excluded due to the fragile condition of his residual limb, and #5 was excluded because he already experienced significant residual limb pain under normal walking conditions. Subject #2 was included, but no pain registered with the application of additional pressure from the inserted disks due to his insensate condition. In total, eight subjects took part in both the PF and painful walking conditions.

Statistical Analysis

Gait data and pain data for all trials of each pain condition were averaged for each subject. To test the

Table 4.
Results of average gait analysis and measurement of pain intensity for subjects during applied pressure trials.

Subject #	Velocity	Cadence	Stride length	Gait cycle	SLS prosthetic	SLS sound	DLS prosthetic	DLS sound	Pain intensity
1	78.1	113	1.38	1.07	0.41	0.41	12.3	11.4	10.8
2	61.0	92	1.33	1.30	0.43	0.54	15.2	10.6	0.0
3	59.8	95	1.26	1.27	0.43	0.47	13.6	15.7	78.8
4	61.2	80	1.54	1.51	0.53	0.59	9.4	16.1	4.0
5	*	*	*	*	*	*	*	*	*
6	53.6	53	2.04	2.29	0.59	0.65	4.6	6.7	33.5
7	*	*	*	*	*	*	*	*	*
8	51.4	97	1.06	1.24	0.44	0.49	16.9	8.7	42.6
9	65.3	111	1.17	1.08	0.41	0.29	24.8	10.9	4.25
10	72.2	107	1.35	1.12	0.37	0.43	17.1	11.4	5.67
11	74.7	102	1.47	1.18	0.45	0.42	15.5	10.0	5.93
avg	64.1	94.4	1.4	1.34	0.45	0.47	14.4	11.3	20.6
SD	9.2	18.6	0.27	0.38	0.07	0.10	5.6	3.0	26.3

Velocity in m/min; cadence in steps/min; stride length in m; gait cycle=time between two initial sequential contacts by the same limb, in s; SLS=single limb support: time for total weight bearing on one leg, in s; DLS=double limb support: time for stance with both feet contacting the floor, as percentage of gait cycle; pain intensity as percentage of maximum; avg=average; SD=standard deviation.

hypothesis that velocity and other gait parameters were dependent on pain, regression analysis with a Spearman rank order correlation (SROC) was performed using the averaged degree of change for each subject across each gait parameter from baseline to painful gait as the dependent variable. The SROC was used to compare the averaged pain data for each subject with the averaged change across each of the gait parameters per subject. The average differences between SLS and DLS times for each subject during baseline and pain production trials were also analyzed with respect to pain intensity using the SROC.

A rank sum test was employed to compare the distributions of each walking parameter for all subjects before and after prosthetic modification, in order to determine whether the walking parameters of painful gait differed significantly from those of PF gait for the same subject group.

In addition, gait data for each subject were grouped as painful or PF walking trials, and the two sets of data were evaluated with a two-sample t-test to test the hypothesis that, for each subject, increased prosthetic pain is associated with a significantly lower velocity, cadence, stride length, and prosthetic SLS time.

Stepwise multivariable regression analysis was performed using each of the gait parameters as dependent variables against all of the other variables for the pooled data, in order to establish that there were no confounding relationships between the gait characteristics and height, weight, sex, age, prosthesis type, or reason for amputation. Furthermore, correlation analysis was performed between age, weight and height, and all gait parameters to rule out confounding relationships. T-test and Chi-square analysis were utilized to rule out confounding relationships between sex and prosthesis type with any of the gait parameters.

RESULTS

The results of the baseline gait measurements for the population shown in **Table 3** were compared to normative data from elderly controls. The majority of our subjects generated gait parameters within that reference range, as depicted in **Table 5** (26).

Table 4 presents the results of the gait analysis and measurement of pain intensity averaged for each subject undergoing applied pressure trials. These gait parameters did not differ significantly from the baseline data. There was a high level of variability between individuals with respect to deviation in gait with the report of pain at the end of the residual limb. With pain, velocity in three subjects increased, while that of five subjects decreased. However, the subject reporting the most pain

Table 5.
Values for nonimpaired gait of controls (95% limits) and gait of persons with transtibial amputation, averaged by age.

Age/Sex	Cadence		Stride Length		Velocity	
	Control range	TTA avg	Control range	TTA avg	Control range	TTA avg
65-80, male	81-125	102.5	1.11-1.71	1.34	48.6-96.6	68.5
65-80, female	96-136	98.0	0.94-1.46	1.06	48-91.4	51.6
50-64, male	82-126	96.8	1.22-1.8	1.35	57.6-100.8	65.3
18-49, male	91-135	86	1.25-1.85	1.48	66-109.2	62.9

Cadence in steps/min; stride length in m; Velocity in m/min; TTA=person with transtibial amputation; avg=average (26).

(78.8 percent of maximum) experienced the greatest change in velocity (18.9 percent slower), while the one reporting the least pain (4.0 percent of maximum) exhibited the least change in velocity (2.7 percent slower). When pain was less than 33.5 percent of maximum, no pattern of gait deviation was evident; however, when pain was greater than 33.5 percent of maximum, all subjects slowed down.

During the pain production trials, the cadence of three subjects increased, while that of four decreased and one stayed the same. The change in stride length for the pain production protocol was also varied, as five subjects increased, and three decreased, their stride length. The changes in gait cycle were slightly different as four subjects increased their gait cycle with pain, three decreased, and one stayed the same.

Changes in the difference between prosthetic and sound limb support time were also affected differently by pain for each individual. Two had a greater difference in SLS for PF trials, five had a greater difference for the painful trials, and one had no change. Only one had a greater difference in DLS during the PF walking conditions, while seven had a greater difference during painful trials.

The SROC analysis for pain intensity as a function of velocity revealed no significant relation. However, the same analysis performed for pain intensity compared with the absolute value of the percentage change (with no differentiation of increase or decrease) between PF and painful velocity revealed a significant correlation ($p=0.046$). The same analysis performed for pain intensity compared with the percentage change in velocity (including positive or negative values) demonstrated a trend but was not a significant correlation ($p=0.058$). Thus, a significant relation was found to exist between pain intensity and the magnitude of change in walking speed. The same analysis between change in stride length as compared to pain intensity was not significant ($p>0.1$).

SROC with pain and differences between the other gait parameters revealed no significant relationships. The rank-sum test employed to analyze the distributions of each gait parameter during PF compared to painful walking trials revealed no significant differences. Correlation of age, height, and weight with the gait parameters revealed no significant correlation. The two sample t-tests and Chi-square analysis between male and female gait parameters revealed no significant differences at $p<0.05$ (two-tailed). No significant difference that could be attributed to sex, age, height, or weight were found in any of the measured gait characteristics; therefore, these data were pooled for all analysis. The females, however, were the lightest and the shortest subjects.

The two sample t-tests analyzing changes in each individual's walking parameters during painful and PF trials revealed a variety of significant differences. Gait parameters for each individual were averaged for all PF trials and compared to the corresponding averages of that subject's gait parameters during painful walking trials. Subjects #11, 10, 9, and 4 showed no significant changes in gait parameters with the report of pain. Subject #8 showed significant decrease in velocity ($p=0.0007$) and stride length ($p=0.013$) and a nonsignificant increase in gait cycle ($p=0.054$) when reporting pain. Cadence change was not significant (0.09). With the report of pain, subject #6 showed significant decrease from PF trials in cadence ($p=0.004$) and significant increases in all of the following: stride length ($p=0.0027$), gait cycle ($p=0.0015$), and difference in SLS ($p=0.005$). Subject #5 did not have a PF walking state for comparison to the baseline painful walking condition. Subject #3 showed significant decreases in velocity ($p=0.016$) and stride length ($p=0.0035$). Ca-

dence and gait cycle changes were not significant (p=0.095). Subject #2 did not report pain despite the augmented pressure applied to the end of the residual limb. Subject #1 showed significant increases in velocity (p=0.015), cadence (p=0.014), stride length (p=0.03), and gait cycle (p=0.0007).

DISCUSSION

It seems apparent from the data that the gait parameters of individual TTAs vary widely in response to painful walking conditions. This variation may be a result of the wide range of different pain intensities reported, or it may be the result of different strategies to avoid the pain. Another possibility is that those who reported low levels of pain did not really experience enough discomfort to alter their gait significantly. Only three reported pain greater than 33 percent, and the next highest pain report was only at 10.8 percent of maximum. The low level pain reports may indicate that the subjects merely noticed the presence of the discs and that the pressure actually experienced was minimal. The minor fluctuations in gait for those reporting 10.8 percent or less pain may, therefore, be normal fluctuations within the range of gait parameters for each given subject. One who reported no pain (0 percent), experienced a 10 percent decrease in velocity during the pressure application trial, a 6 percent decrease in stride length and a more even (regular) SLS and DLS time. Clearly some factor was affecting the gait, despite the report of zero pain. This suggests that even without a report of pain or discomfort, gait may change due to a factor not measured in our study, such as individual abilities to acclimate optimally to minor changes in the feel or fit of the prosthetic device as would occur with our pressure application discs.

In summary, subjects experiencing pain of 33.5 percent or greater all slowed down, which may indicate that pain will only significantly affect gait if its intensity exceeds a threshold level. This possibility will require further study. Future studies may need to focus on subjects who experience intense transient pain during times of baseline gait so that their gait parameters at that time could be compared to their normal gait during a PF period. The pattern of decrease in velocity for those reporting greater than 33 percent maximum pain was expected for a variety of reasons. One reason is that subjects have reported modifying their gait in order to reduce pain; a reduction of force at the residual limb end reduces the pain stimuli. Furthermore, gait velocity is reduced to avoid increasing oxygen consumption above normal limits, as may occur with compensatory movements aimed at reducing the pain (4).

There are several confounding variables in studies that seek to investigate gait characteristics of TTAs. Residual limb length is one such factor (4), and others include varying degrees of joint mobility, limb length, muscular control, and proprioception, especially the awareness of foot contact with the floor (30,31). The combination of these factors may have significant effects on individual TTAs, and it would require a larger study than this preliminary report to adequately account for these. A larger study would also allow investigators to employ a more homogenous population of subjects who use the same prosthesis type. Such a study could separate TTAs secondary to trauma from those secondary to vascular insufficiency, as there are major differences between these two populations. An increased subject pool will enable investigators to exclude subjects with sensory neuropathy, prior pain, or a fragile residual limb end, so that these potential confounding effects will be eliminated.

Despite the potential confounds identified above, the investigators wish to emphasize that the intent of this preliminary study was to examine the relationship between gait characteristics and perceived pain—the threshold for a noxious stimulus is certainly different between those with a sensory neuropathy and those without; however, once the pain registers on the visual analog scale at a given value, this discomfort level is then perceived and reported as the same between two individuals regardless of the amount of physical stimuli needed to bring perception to that level. In other words, someone with a sensory neuropathy may require a larger pebble in his shoe than someone without the neuropathy, but if both individuals report 4 out of 10 level of pain, then it seems reasonable to test whether their gait changes in a predictable manner.

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