ICNSJ Original Article

The Need for Stump-Socket Interface Pressure Measurment during Bidirectionally Perturbed Stance In Transtibial Amputees

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ABSTRACT

Recent studies show significant reduction of postural stability in transtibial amputees (TTAs) especially when a perturbation is applied. However, no record has been seen on the consequences of such perturbation on the Stump-Socket Interface Pressure (SSIP). Our objective was to investigate whether such perturbation impose excessive pressures on the stump. We were also interested on the type of the response and direction in which TAs may face more difficulties. A 52-year-old TA participated in the study. The trial was performed using a custom bidirectional perturbing mechanism in the pitch and roll axes of ankle. Center of Pressure and were recorded by two force platforms and five resistive pressure sensors respectively. Right and anterior perturbations imposed the maximum SSIP while several CoP measures were considerably greater for the prosthetic leg just in left perturbations. This supports the necessity of measurement of SSIP as well as CoP to provide a better understanding about the new situations of TAs in postural stability.

Keywords: postural stability; prosthesis; soft tissue; perturbation

ICNSJ 2015; 2 (1):8-11 www.journals.sbmu.ac.ir/neuroscience

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Received: July, 24, 2014 **Accepted:** November, 11, 2014

INTRODUCTION

Postural stability is important both for understanding motor mechanisms underlying the control of body segments during standing[1] and evaluating and predicting risk factors of losing balance (i.e., falls, slips, etc.)[2]. Postural stability is mainly maintained using feedbacks provided by vision, vestibular and somatosensory mechanisms. On the other hand, musculoskeletal system and specially muscles relating to ankle and hip joints are responsible to compensate applied perturbations to the center of mass and make it back to its stable conditions[3]. It is also suggested that quiet postural analysis may not be a good predictor of falls and so implementation of perturbations become popular in the recent studies[4].

Many psychological, nervous or musculoskeletal problems can significantly affect human normal stability condition[5]. For instance, Lower Limb Amputation (LLA) is one of the condition that affect the sensory information as well as huge costs to the musculoskeletal system[6]. Since ankle joint is believed to be responsible for the compensation of Anterior-Posterior (A/P) perturbations[3], it is proposed that substitution of the intact ankle with a prosthetic one in TTAs would result in changes in stability conditions mostly at A/P direction while Medio-Lateral (M/L) stability would not change significantly[7]. Hence, further studies are dedicated to the analysis of postural stability of TAs mostly when perturbations in A/P direction are applied. These studies confirm significant reduced postural stability of TAs compared to the controls[8-10].

Moreover, condition of the stump (i.e. the remaining part of the limb that interact with the prosthesis) also can play a critical role in TAs postural stability. In fact, mechanical stresses applied on the stump due to perturbations may result in acute pain and even inflammation that is the source of discomfort in TTAs[11]. Therefore, these stresses should be considered as an additional input that must be controlled and maintained within a defined limit during postural control. In this study, it was aimed to investigate whether consideration of this parameter (i.e., maximum stress) provides additional information for postural stability analysis. We also were interested to find out which direction of perturbation can result in the maximum stress on the stump.

MATERIAL AND METHODS

Experiment Procedure

A 52-year-old male TA with stump length of 15 cm participated in the study. The subject had no previous records of any psychological, nervous or critical musculoskeletal problems that needed medical treatments for the past 4 years. The stump was instrumented using five Pliance pressure resistive sensors (Novel GmbH, Germany), on the anatomical weight-bearing landmarks (Figure 1)[12]. Then the participant was asked to stand on a custom-designed bidirectional perturbing mechanism which involved two portable Kistler 9286BA force platforms (Kistler, Switzerland) in a way that each foot was placed on one force platform and parallel to the rotation axes. Perturbations were applied randomly in pitch (A/P) and roll (M/L) axes of the ankle for the maximum amplitude of 5°. In general, 16 perturbations (4 trials x 4 directions) were applied and data was collected during the whole experiment at 200 Hz from the force platforms and at 50 Hz from the pressure sensors.

Data Analysis

Data analyses were done using Matlab (ver. 7.11, Mathworks, USA). First, data of each perturbation was extracted and then categorized based on the perturbation direction ($roll^+$, $roll^-$, $pitch^+$ and $pitch^-$). The plus and minus sign is in accordance to the right-hand law and therefore can be interpreted as right, left, anterior and posterior respectively. Afterwards, CoP measures (Standard Deviation, Excursion, Velocity and Range) were calculated for each trial[13]. Weight-Bearing Ratio (WBR) of intact limb to the prosthetic limb was calculated for each trial from normal component of force platform data. Also, maximum pressure (MaxP), minimum pressure (Min P) and the time fraction that pressure was at the 10% vicinity of MaxP were calculated for each pressure sensor in each trial (t_{90+})[12]. Statistical analysis were done using Student-t test with confidence interval of 95% by SPSS (ver. 21, IBM Inc., USA).

RESULTS

The means of CoP and SSIP variables are summarized in Table 1. WBR of intact limb to the prosthetic limb is significantly higher than for the trials in $roll^+$, $pitch^+$ and $pitch^-$ directions. Furthermore, all the CoP measures of the prosthetic limb at $roll^-$ were higher than those of intact limb (Table 1).

Pressure was at its highest value at the $roll^+$ and $pitch^+$ directions. Popliteal pressure was higher than the other

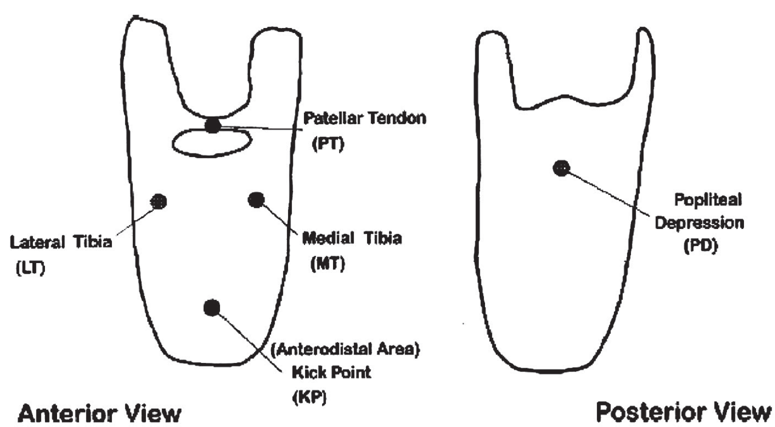

Figure 1. Places that pressure sensors are attached to the stump. a: common anatomical landmarks for weight bearing regions. Adapted from[12], b: example of sensor placement on the participant's stump.

Table 1. Summarized CoP and Pressure mean values for each perturbation. Excursion, Range and CopSD are calculated in *m*, while CoP Velocity is calculated in *m/sec*. WBR and t_{90+} has arbitrary units. Both MaxP and MeanP are measured in kPa.

	Roll+ (right) perturbation		Roll- (left) perturbation		Pitch+ (ant.) perturbation		Pitch- (post) perturbation	
	mean right	mean left	mean right	mean left	mean right	mean left	mean right	mean left
Excursion	0.786	0.653	0.265	1.840	0.506	0.664	1.329	1.316
CoP SD								
x	0.023	0.016	0.005	0.054	0.005	0.011	0.014	0.014
y	0.021	0.011	0.007	0.034	0.022	0.028	0.051	0.043
CoP Vel.	2.761	2.237	0.780	5.411	1.790	2.370	4.643	4.628
Range								
x	0.098	0.094	0.053	0.414	0.058	0.089	0.086	0.106
y	0.095	0.072	0.026	0.149	0.095	0.120	0.214	0.221
WBR	0.76		4.11		1.43		1.15	
MaxP								
MT	65.00		56.88		37.50		52.50	
PT	117.50		111.88		85.00		134.38	
LT	79.38		88.75		59.38		67.50	
KP	66.25		49.38		46.25		49.38	
PD	491.88		219.38		507.50		272.50	
MeanP								
MT	23.21		27.09		29.46		40.50	
PT	58.36		63.97		42.32		119.48	
LT	30.43		42.32		45.98		50.80	
KP	32.27		33.79		37.54		35.61	
PD	241.40		153.27		328.59		177.00	
T90+								
MT	0.08		0.32		0.25		0.13	
PT	0.14		0.36		0.14		0.54	
LT	0.08		0.34		0.22		0.13	
KP	0.08		0.41		0.14		0.14	
PD	0.12		0.33		0.11		0.12	

four sensors in every trial. This is in accordance to the previous studies regarding the SSIP values for walking and stair ascent/decent trials[12, 14]. T_{90+} was relatively small and did not exceed 0.2 in any sensor/direction.

While reactions to perturbations are mostly started with a peak at the prosthetic side, for the roll$^-$ perturbation, force and pressure signals drop first because of the unloading of prosthetic limb due to the nature of perturbation (Table 1).

DISCUSSION

Substitution of the intact limb with a prosthetic leg can lead to changes in postural stability in TTAs. Hence, the risk of falls in lower limb amputees are 20% more than healthy populations[15,16]. This can be resulted from the inherent differences between natural and prosthetic ankles as well as the loss of sensory inputs. However, as suggested by the current experiment, the possibility of additional effects induced by excessive SSIP on the motor control strategies should not be neglected. In fact, sensitivity of the skin and underlying tissues at the stump area can change balance control strategy to minimize applied stress on the tissue.

Also, the current study suggests different behavior of the prosthetic leg at pitch and roll directions which must be taken into account in further studies. Separate force platform for each foot is critical to see behavior of intact and prosthetic foot during the experiment. Furthermore, SSIP were maximum in both roll and pitch directions. Therefore, unlike the previous studies[7], postural analysis of the response to both pitch and roll perturbations seems to be necessary.

Pressures higher than 150kPa applied on the surface of skin are considered harmful or destructive to that tissue[17]. As it is revealed in this study, nearly all of the pressure values were higher than this limit for each perturbation. However, it is not still clear that whether peak stress, duration of application, stress gradient or even a combination of these factors causes pain or inflammation of stump tissue[17]. Therefore, further studies for investigation of the main sources of injury and discomfort of amputees' stump are necessary.

This study suggests further postural stability analyses of lower-limb amputees using bidirectional perturbation to investigate effects of such perturbations in daily life on their balance performance as well as condition of their stump. This is achieved by doing experiment on more participants and taking other conditions such as prosthetic design, amputation level, age and daily performance into account.

ACKNOWLEDGMENT

All the experiments were performed at the Biomechanics laboratory of Ergonomics Department, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran. The authors would like to thank Ms. Hoda Nabavi and Dr. Farhad Tabatabaei for their help in data collection. Authors also express their gratitude to Professor Mohammad Parnianpour for his generous supports and consultation throughout this study and to Mrs. Banooashraf Saberi and Mr. Esmail Seddighi for their great participation in editing this manuscript.

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