Plantar Pressure in Transtibial Amputees

LELY A. LUENGAS, MIGUEL A. GUTIERREZ
Tecnología Electrónica
Universidad Distrital Francisco José de Caldas
Cra 7 # 40B-53, Bogotá
COLOMBIA
laluengasc@udistrital.edu.co

Abstract: - Prosthesis is the preferred method for the rehabilitation of the amputee and prosthetic fitting requires processes and based on knowledge of the biomechanical behavior of the prosthesis wearer procedures. Thus, understanding the adaptions that occur due to the loss of lower limb is an important aspect in devising a successful rehabilitation program. Therefore, in the Service Amputees and Prostheses at Hospital Militar Central we did a cross sectional descriptive study with observational component for measuring distribution of plantar pressure in patients transtibial amputees due to trauma by land mines. The study population consisted of seven men with unilateral transtibial amputation, aged 29 and 40 years with proper use of prostheses for over a year, with appropriate adaptation, prosthesis with suspension liner and pin and foot in carbon fiber. Distribution of plantar pressure was measured during standing using shoe insoles with 99 capacitive sensors. Foot plantar pressure is the pressure field that acts between the foot and the support surface during everyday locomotor activities. Information derived from such pressure measures is important in posture research for diagnosing lower limb problems, prosthesis alignment and other applications. All patients showed a pressure distribution asymmetry of the foot plantar soft tissue under each foot. In the non-amputated side pressure is greater in the heel and midfoot, while in the amputated side pressure is in the head of the first metatarsal and the medial heel.

Key-Words: - Amputation, biomechanics, plantar pressure, prosthesis, standing

1 Introduction

After Afghanistan, Colombia has the second highest casualty rate of landmine victims in the world, with more than 11,621 people killed (2285 people) or injured (9336 people) by landmines since 1990, according to the Presidential Program for Comprehensive Mine Action dependence of the Administrative Department of the Presidency of the Republic. Of the total casualties, some cases resulted in the amputation of lower limbs being the most common transtibial amputation, where a loss of one or both legs below the joint knee [1]. In the case of a unilateral amputee, the individual comes to have an asymmetric structure with alteration in sensitivity and muscle loss in the amputated side [2]–[4].

The distribution of body weight in static and dynamic conditions is one of the main functions of the lower limb, as this stability is provided to perform different tasks. The shift in weight on the limbs during stance and gait is relevant to people with lower limb amputation clinical problem. Due to the loss of limbs, the center of gravity moves laterally towards the side of the amputated limb not given a change because the prosthesis does not completely offset the lost mass, this also influences the balance. The absence of all or part of a lower limb proprioceptive reduces the amount of information on areas in which the foot is at rest and the precise location of the prosthetic limb, which influences the position [3]–[7].

Several reports have identified aspects of plantar pressure and the location of the center of pressure. Foot plantar pressure is the pressure field that acts between the foot and the support surface during everyday locomotor activities. Information derived from such pressure measures is important in posture research for diagnosing lower limb problems, prosthesis alignment and other applications. Limited data of characteristics of equilibrium and stability of adult amputees have been reported [8], [9], but information on the distribution of plantar pressure is almost nonexistent.

In Colombia, study in this area is almost zero, no evidence of analysis of biomechanical parameters in transtibial amputees because of landmines and are prosthesis wearers. For this reason it is vital to conduct research in the area and identify the biomechanical behavior when using a transtibial prosthesis. The purpose of this study was to determine the distribution of pressure on the plantar surface in adults unilateral transtibial amputees caused by landmines trauma prosthesis wearers.

2 Methods

In order to evaluate plantar pressure in the standing position in amputees subjects a study in Hospital Militar Central, Bogotá, Colombia, was carried out.

Seven volunteers were recruited for this pilot study. Subject characteristics are seven men, mean age 33.28 ± 3.8 years (mean ± SD), range 29–40 years. All subjects were screened with medical history. Inclusion criteria were: age range 20–40 years, unilateral amputees because of trauma by landmines, prosthesis wearers with liner and pin suspension and carbon fiber foot high activity, proper use of prostheses for more than a year and independent walking transtibial. Exclusion criteria were: neurological or musculoskeletal abnormalities in other extremities, peripheral neuropathies, skin lesions, secondary alterations in motion by pain, use of external aids to walk, disorders in other segments joint of the lower limbs. The study was performed in the Service Amputees and Prostheses at Hospital Militar Central, Bogotá, Colombia, and all subjects signed informed consent approved by investigators. Approval was obtained by the local Medical Research Ethics Committee.

An in-shoe based foot plantar pressure sensor by Pedar© Novel (Pedar® system, Novel, Germany) was used. In-shoe sensors are flexible and embedded in the shoe such that measurements reflect the interface between the foot and the shoe [10]. A 2D guide drawn on the floor was used to control foot and body position, following the anatomical position. The measurement system was mounted in a room of the Service Amputees and Prostheses at Hospital Militar Central, with constant access to the complete experimental setup: a computer, a standing lamp, and the guides.

At the beginning of every session, a medical doctor examined the subjects, focusing on their lower extremities. Height and body mass were measured. Subjects received instructions on how to stand on the 2D guide. Session consisted of three measurements, Fig. 1.

All data were visually inspected prior to analysis to assure high quality of data acquisition. Time-series pressure measurements for all sensors were grouped into nine anatomical masks. These masks corresponded to the following anatomical areas: 1. hallux, 2. toes two and three, 3. toes four and five, 4. first metatarsal, 5. metatarsals two and three, 6. metatarsals four and five, 7. arch, 8. medial calcaneus, 9. lateral calcaneus.

The two variables were calculated for the each mask: maximum pressure and mean pressure. The variables were calculated for each trial and then averaged. Maximum pressure was defined as the greatest pressure any single sensor in each mask measured in a single trial, and these values were averaged separately for each mask over three trials. Mean pressure was defined as the average of all activated sensors in a mask for a single trial.

Fig. 1. Procedure to evaluate plantar pressure in transtibial amputees.

Data were explored by the intra-subject outliers, using the SPSS statistical software. The independent variables were each session and each foot; the dependent variable was pressure distribution on each foot. Data were summarized using the mean and standard deviation. Analysis of variance (ANOVA) was used to investigate the variability of pressure in the different regions in each of the subjects analyzed. Standard deviations of the differences between measures identified in the ANOVA were used to determine the coefficient of repeatability (CR) for each parameter. Repeatability was investigated for amputee and non-amputee side separately. The maximum and mean pressure were compared between the subjects for all masks. In addition, we compared the mean and maximum pressure in the medial masks (medial calcaneus, arch, first metatarsal, and hallux) to the lateral masks (lateral calcaneus, arch, second and third metatarsal, and toes) and between the subjects. We also compared the anterior masks (hallux, toes, first metatarsal, second and third metatarsal, and fourth and fifth metatarsals) to the posterior masks (arch, medial calcaneus, and lateral calcaneus).

3 Results

Fig. 2 shows distribution of pressure in standing. Fig. 2A shows distribution of no-amputee side and 2B amputee side.

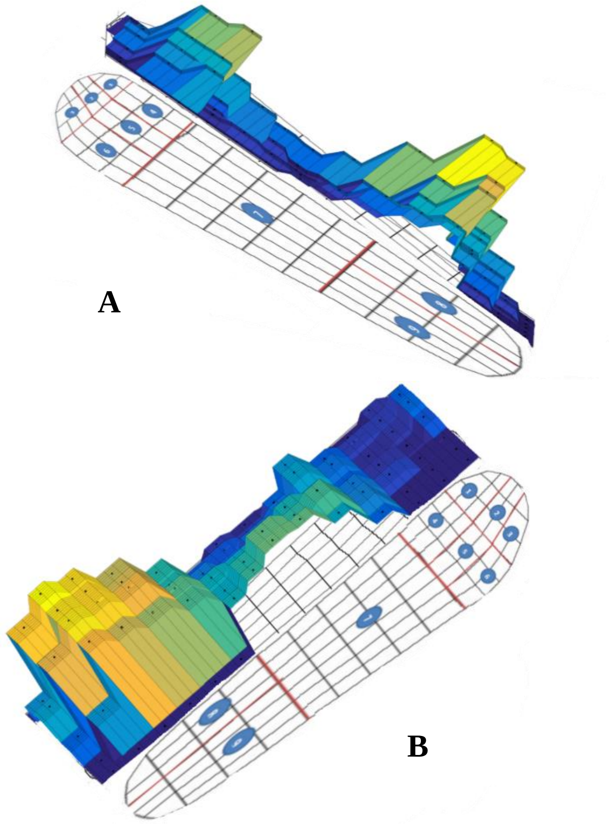

Fig. 1. Foot pressure distribution. Maximum pressure distribution on all sensors during standing and the nine anatomical masks superimposed on the insole. Mask are: 1 Hallux, 2 toes two and three, 3 toes four and five, 4 first metatarsal, 5 metatarsals two and three, 6 metatarsals four and five, 7 arch, 8 medial calcaneus, 9 lateral calcaneus. A. Left foot, amputee side. B. Rigth foot, no-amputee side.

Repeatability coefficient (expressed as a percentage of the average) was less than 10% in parameters in each subject, which allows for data obtained from the measurements are reliable. Foot pressure distribution was highly significantly different between masks for the amputee side and no-amputee side for all variables (maximum and mean pressures $p < 0.00001$). Differences in the foot pressure distribution between feet for the maximum and mean pressures were confined to the calcaneus region and to the medial masks of the foot.

Fig. 3 shows the differences in maximum pressure distribution for all 9 anatomical regions for each foot.

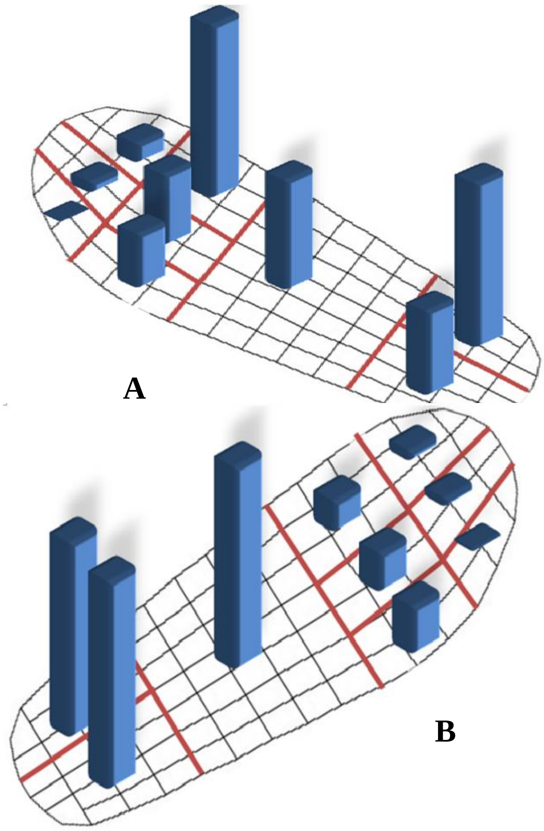

Fig. 2. Pressure distribution by anatomical region. Average pressure distribution for the amputee side and no-amputee side for each anatomical region. A. Left foot, amputee side. B. Rigth foot, no-amputee side.

Fig. 4 shows comparison between amputee and no-amputee side, the higher maximum pressure was in region 4 in amputee side. Amputee side had higher pressure in six regions (1, 2, 4, 5, 6, and 8 region) of the nine anatomical regions versus no-amputee side.

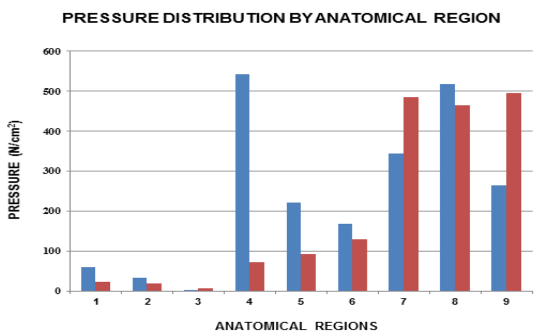

Fig. 3. Pressure distribution by anatomical region, comparation between two feet. Blue is amputee side and red no amputee side. Amputee side pressure is higher than no-amputee side. Region 4 (first metatarsal) in amputee side was the highest pressure.

No-amputee side had lower maximum pressure in the anatomical region 3. In the lateral calcaneus region (region 9) had higher maximum pressure. Pressure in regions 7 and 8 were just smaller than region 9. In metatarsal region masks, the no-amputee side had reduced pressure. Pressure of lateral region was generally greater than medial region. In all anterior region masks, the no-amputee side exerted low pressure. Consequently, posterior region had higher pressure than anterior region.

In amputee side the higher maximum pressure was in region 4. Anatomical region 3 in amputee side had lower maximum pressure. In metatarsal region masks, the amputee side had reduced pressure. In all lateral masks, amputee side exerted low pressure. Consequently, medial region had higher pressure than lateral region. Pressure had a slightly difference between anterior and posterior region.

In anterior region feet displayed reduced pressure. Medial calcaneus region not was significantly different between amputee side and no-amputee side. Pressure over lateral anterior region (3 and 4 regions) was not different between feet. In general, the first metatarsal had the higher pressure on the side amputee, in contrast to the contralateral where the higher pressure was located in calcaneus.

4 Conclusion

Human static standing is an asymmetric event and not uniform. A large variability in reaction forces and balancing activity present in every person in the position described.

The help of this study was to examine the effects of transtibial amputation on the plantar pressure distribution. Nine anatomical regions were defined in the foot, which were optimal for analysis. Regarding the reproducibility of measurements of pressure distribution, registered standing static conditions, the results show high within subject reproducibility, reflected in correlation coefficient values of intra-class. The use of the 2D guide used to register plantar pressure produced less variation among same subject measurements over the course of the measurement sessions. Better results for the acquisition of repeatable measurements are observed with the 2D guide.

We found existing asymmetries in pressure between amputee side and no-amputee side. The study has shown that no-ampuee side exert less pressure under anterior masks of the foot (hallux, toes and metatarsals). This implicates that subjects preferentially bear weight on the posterior foot (more than 50% of the total foot pressure). Lateralization of foot pressure suggested that medial weight bearing is limited in no-amputee side compared to amputee side. Well-distributed weight bearing and foot pressure compensate for the forces and heavy loads imposed on the foot during quiet standing. In the anterior masks, the amputee side exerted higher pressure (25% of the total foot pressure) and force on the first metatarsal region, this may be due to type of prosthesis.

Technique used in this study is suitable for assessing distribution of plantar pressure in patients with transtibial amputation, in addition to medical staff provides an insight into the behavior of the pressure in a patient with transtibial amputation because of mines user mines and prostheses.

The findings reported here are specific to transtibial prostheses and prosthesis type. The participants in this study had all used prosthesis with liner and pin suspension and carbon fiber foot high activity.

References:

[1] Dirección Contra Minas, “Víctimas de Minas Antipersonal y Municiones sin Explosionar,” *Presidencia de la República de Colombia*, 2018. [Online]. Available: http://www.accioncontraminas.gov.co/estadisticas/Paginas/victimas-minas-antipersonal.aspx. [Accessed: 03-Oct-2018].

[2] C. D. Tokuno, D. J. Sanderson, J. T. Inglis, and R. Chua, “Postural and movement adaptations by individuals with a unilateral below-knee amputation during gait initiation,” *Gait Posture*, vol. 18, no. 3, pp. 158–169, Dec. 2003.

[3] M. Lord and D. M. Smith, “Foot loading in amputee stance.,” *Prosthet. Orthot. Int.*, vol. 8, no. 3, pp. 159–64, Dec. 1984.

[4] L. A. Luengas, G. Sanchez, and K. Novoa, “Prosthetic alignment and biomechanical parameters in transtibial amputees due landmines,” in *IFMBE Proceedings*, 2017, vol. 60.

[5] L. A. Luengas C., M. A. Gutierrez, and E. Camargo, *Alineación de prótesis y parámetros biomecánicos de pacientes amputados transtibiales*. Bogota: UD Editorial, 2017.

[6] S. Blumentritt, T. Schmalz, R. Jarasch, and M. Schneider, “Effects of sagittal plane prosthetic alignment on standing trans-tibial amputee knee loads.,” *Prosthet. Orthot. Int.*, vol. 23, no. 3, pp. 231–238, 1999.

[7] N. Vanicek, S. Strike, L. McNaughton, and R. Polman, “Postural responses to dynamic perturbations in amputee fallers versus

nonfallers: a comparative study with able-bodied subjects.," *Arch. Phys. Med. Rehabil.*, vol. 90, no. 6, pp. 1018–25, Jun. 2009.

[8] D. C. Morgenroth, A. D. Segal, K. E. Zelik, J. M. Czerniecki, G. K. Klute, P. G. Adamczyk, M. S. Orendurff, M. E. Hahn, S. H. Collins, and A. D. Kuo, "The effect of prosthetic foot push-off on mechanical loading associated with knee osteoarthritis in lower extremity amputees.," *Gait Posture*, vol. 34, no. 4, pp. 502–7, Oct. 2011.

[9] A. H. Abdul Razak, A. Zayegh, R. K. Begg, and Y. Wahab, "Foot Plantar Pressure Measurement System: A Review," *Sensors*, vol. 12, no. 7. pp. 9884–9912, 2012.

[10] Novel.de, "The pedar® system," 2006. [Online]. Available: http://www.novel.de/novelcontent/pedar. [Accessed: 11-May-2014].