

Influence of body weight and prosthetic flexible ankle on walking balance parameters in transtibial amputee gait

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Abstract. The walking balance of transtibial person has been widely documented in many literature. However, the effect of walking balance of transtibial amputee between body weight and a prosthetic foot is not widely known. This study was used for gait analysis to measure the walking equilibrium parameters amputated from 14 people with transtibial. To reduce variability among subjects at the time of testing, we carried out washing out for all subjects for 2 days. Data generated that all subjects walked in one direction straight to measure the walking balance and kinetic parameters. Design experiment with a crossover design, subjects with amputations walked for a distance of 80 meters, estimated time of 6 minutes and speeds about 1.20 to 0.15 m per sec, during the gait phase. The movement of the ankle in the plantar flexion position is reduced because in the final phase, the standing ankle becomes flexible. Correlation analysis shows that the effect of walking balance when wearing a prosthetic foot is measured during 1 gait cycle. The results depend on the design of prosthetic foot and how to walk.

1. Introduction

Indonesia as a lower country based on the results of the Sosial Ekonomi Nasional Survey (Susenas) in 2012 explained that as many as 616,387 people had lower limb amputations [1]. The number of amputations in the lower limb is 20 times compared to amputations of the lower limb. The occurrence of lower limb amputations is mostly caused by traffic accidents and in the age group of fewer than 50 years [2]. There are many prostheses available on the market, often an orthopedic doctor in Indonesia in giving advice to a transtibial amputation to use a conventional prosthetic foot. This condition is caused by their purchasing power. In fact, we know that the use of conventional prosthetic feet, felt by transtibial amputation to walk on a flat surface, is still difficult, due to limited mobility of prosthetic ankle joints [3]. Ambulation of transtibial amputees walk on level surfaces differs from the normal population. Now in Indonesia many prosthetic feet are available to meet the needs of amputated individuals. The design and material have spurred the manufacturing of prosthetic lower limb legs, specifically the prosthetic ankle design. This design is made close to the biological ankle in order to produce more strength and mechanical energy. Whereas conventional prosthetic feet with passive ankles are the most commonly used [4,5]. The use of passive prosthetics, amputation of the lower limbs constantly attempts to adjust gait. This condition is indicated by an increase in user's metabolism, asymmetrical gait, and cadence walking between irregular legs [6,7].

The design of prosthetic feet grows in complexity, which is mainly how to design flexible ankles. The design of this prosthetic ankle should be designed to be able to store mechanical energy during



loading and release energy when the load is released [8]. When the price of a prosthetic foot become increases due to excess in one component design. So it is necessary, how to justify the use of these components. It is important to understand the design characteristics of prosthetic foots during gait so that its benefits can be evaluated. On the other hand, gait analysis of an amputee has done a lot of research, which aims to compare different prosthetic foots. Several studies have been interested in evaluating various underfoot knees used by amputees [9,10,11]. This study also tested the amputee walking on various prosthetic foots with several biomechanical parameters. This was done to determine the effect of the amputee gait between different body weights and prosthetic foots. The research looks at specific forces that occur during amputee gait. Normalize these forces by linearly scaling them to body weight, height as a way to normalize the joint moments [12,13]. Biomechanical models of balance are now emerging. The kinetics of movement in humans can be seen from the integrated control in each joint of all members of the body.

Kinetic definitions are variables that cause walking patterns to be specific and we can observe or measure [14]. Kinetic movements include forces and moments that affect internal forces and moments during walking between the body and the environment, patterns of mechanical strength in muscles (rate of absorption by muscles, or rate of movement of forces between segments) [15]. Kinetics is a form of analysis that is repeatable and accurate when examining gait in a person [16,17]. The strength of the body's reaction has been used in descriptive analysis on human gait [18]; more recently walking balance has been used to establish predictors of the success of prosthetic foots. This method emphasizes the human equilibrium pendulum model [19]. The resulting force, it's calculated from each connection kinetics [20], was identified as an important parameter related to prosthetic foot development and gait analysis.

Walking balance is a term in describing the dynamics of posture to prevent loss of body balance when walking so as not to fall. This is related to the inertia force on the body and the inertia characteristics of body segments, and posture has been described as the center of the orientation of each body segment that moves relative to the vector [18]. This was explained by Winter that the walking balance system is a way to measure the extent of the human walking response. According to Ivanenko and Gurfinkel, there are three sensory systems in balance and posture consisting of visual, vestibular, and somatosensory systems. The visual system is a system that is involved in planning one's motion along the way. The vestibular system is known as a 'gyro', this movement that senses linear motion and angular acceleration. While the somatosensory system is a sensor that senses the position and velocity of all body segments including contact with surrounding objects (including the ground) and the center of gravity orientation.

Transtibial amputees employing active with flexible ankle prostheses have shown significant improvements in gait and walking balance when compared to passive prostheses [22, 23]. With a prosthetic foot and ankle, the amputee lacks active dorsiflexion, plantarflexion, strength, and power resulting in gait abnormalities [24,25]. Limitations of prosthetic foots affect the mechanics of the stump below the knees and hips and require compensation with flexible ankles [26]. The SACH foot will receive a posterior load, where the ankle is in the plantar flexion position while receiving a load response, whereas a stiff ankle prevents plantar flexion from taking off [26].

The measurement of walking balance, when the foot is placed in a symmetrical standing position, can represent the effect of the prosthetic foot during walking. Therefore, there is still little research attention regarding the effects of weight on gait. Weight body can influence in a single support phase. The study indicates that body weight and the type of prosthetic foot affect the asymmetrical movement's characteristics of a person with a transtibial amputee. Furthermore, differences have been found between the peak and integrated forces applied to prosthetic foot during amputee gait.

The aim of this study was to evaluate the effect of transtibial amputee body weight on the prosthetic foots used before each amputation test was examined with prosthetic foots themselves. Testing is done with a protocol to record the overall kinetic data of the body and the running balance. This test focuses on the walking balance of the transtibial amputee in wearing prosthetic foots without and with flexible ankles and their relationship to weight parameters.

2. Research method

The Sebelas Maret University Ethics Committee of Surakarta has agreed to test the transtibial amputee with protocol number: 638 / XI / HREC / 2014 and prior informed consent was obtained; adaptation and clarification with testing, technical and testing procedures submitted to them before testing is carried out [27-28].

2.1. Subject

Subject inclusion criteria: walk straight to the shuttle walk; amputee at least one year after post-amputation; functional ambulation independently; and do not have pathological conditions that affect walking balance. The condition of amputation was caused by trauma ($n = 9$), vascular ($n = 2$), and congenital ($n = 3$).

Table 1. Individual descriptive details for 14 participants.

Subject Characteristics	Body Weight < 64.04 kg ($n = 7$)		Body Weight > 64.04 kg ($n = 7$)	
	Mean \pm SD	Median (Min-Max)	Mean \pm SD	Median (Min-Max)
Age (yrs)	29.29 \pm 6.55	32.00 (20.00 - 38.00)	25.71 \pm 8.20	23.00 (19.00 - 41.00)
Weight (kg)	60.79 \pm 2.51	61.41 (57.02 - 63.35)	71.25 \pm 7.82	67.65 (64.04 - 86.23)
Height (cm)	159.00 \pm 6.81	160.00 (145.00 - 165.00)	168.43 \pm 5.28	170.00 (161.00 - 176.00)
Prosthetic use (yrs.)	9.14 \pm 5.15	9.00 (1.00 - 14.00)	7.14 \pm 7.88	2.00 (1.00 - 20.00)
Stump length (%)	32.92 \pm 14.72	30.23 (18.89 - 62.22)	37.38 \pm 15.73	37.50 (15.56 - 65.71)

2.2. Apparatus

The study was performed in a product design and development laboratory, which is equipped with a 20 m long walkway. We recorded the amputee gait process with Canon EOS 1100D DSLR camera with 120 frames per second video recording, a JVC Everio camcorders camera GZ-MG760 video resolution of 640×480 pixels. Walk motion analysis is digitally recorded using the lower limb markers with the right and left foot. Kinetic data were recorded using an electrogoniometer which is useful for measuring the angles of joints mounted on lower limb segments with an accuracy of 0.01 [28]. The gait amputee for left and right amputation has been determined in a previous investigation [27]. Kinetic data were normalized based on subject weight [29-31].

2.3. Experimental protocol

Subjects performed overground walking trials along with a ten meter with the shuttle walk to the walkway as much as eighth time at speed of around 1.20 to 0.15 m/s [16, 32]. The biomechanical approach to movement analysis for walking balance, with the static movement, observed [33]. Walking balances were normalized to each subject's stride length. The walking balance is obtained by subtracted force resultant for intact leg by amputated leg during gait for each of six phases, and then walking balance (N) is intact leg – prosthetic foot [34]. It is showed that the smaller the difference between the intact leg with a prosthetic foot, showing an amputee to walk more balance. Each subject wore his own prosthetic foot. The order of testing was randomized such that each walking speed was performed first on the overground. The prosthetic foot for testing is determined according to the size of the individual anthropometric data including the height, weight, and level of activity of the subject, and is attached to the socket and subject's own suspension. Feet were classified according to their design. Two different configurations of prosthetic feet were used by the amputees in the group (Table 1). The prosthetic foot combination provides additional movement in the sagittal plane and is used to observe the effect of the prosthetic foot on the kinetic motion. The experimental design was conducted a crossover design between Period I and Period II [35]. Data were collected while subjects walked

with two prosthetic configurations: the exoskeletal prosthetic foot that does not have an ankle system (PL1) and endoskeletal prosthetic foot with the flexible ankle (PL2). The flexible ankle is multi-axis foot, in contrast, feet that are designed with an energy store-return system. The prosthetic foot has been aligned with the same prosthetic condition; PL1 was always tested before PL2. The period I, group I is PL1 and group II is PL2. Furthermore, period II, group I was continued to PL2 and group II was continued to PL1. Subjects were permitted two days for acclimation prior to data collection.

2.4. Statistical analysis

The results of the kinetic data recording were then averaged over all fourteen subjects of transtibial amputation. Two-way ANOVA used to analyse statistically between differences in amputee body weight, effects of prosthetic foot use, and interactions of body weight and wearing the prosthetic foot. Independent t-test used to compare amputee data and body capabilities. Relationship between two variables was assessed by Pearson's Correlation. Data normality and homogeneity were confirmed using the Shapiro-Wilk and Levene's test, respectively. IBM SPSS version 20 was used for statistical analysis and critical alpha was set at 0.05.

3. Result and discussion

3.1. Result

A total of 14 subjects with transtibial amputations were involved in the study. Their average age was 27.50 years (SD ± 7.37 years). Their average height and mass were 163.71 cm and 66.02 kg, respectively. Seven amputees used flexible prosthetic ankles to help walk during their gait analysis; Other subjects walk with assistive devices (Figure 1).



Figure 1. Prosthetic foots with the flexible ankle in design multi-axis and energy store-return.

Data normalization method to use variable body weight and body height in accordance with previous studies [36], it is to eliminate differences caused by variations in weight and height, so that the mechanics of walking can be expressed [30]. Observations on the subject were made on the sagittal plane of the subject being analysed. The results showed that each the subjects The results showed that each the subject explains to reasonably good symmetry during gait between the intact leg and prosthetic foot for two prosthetic foot difference, had similar walking balance for both body weights (Figure 2).

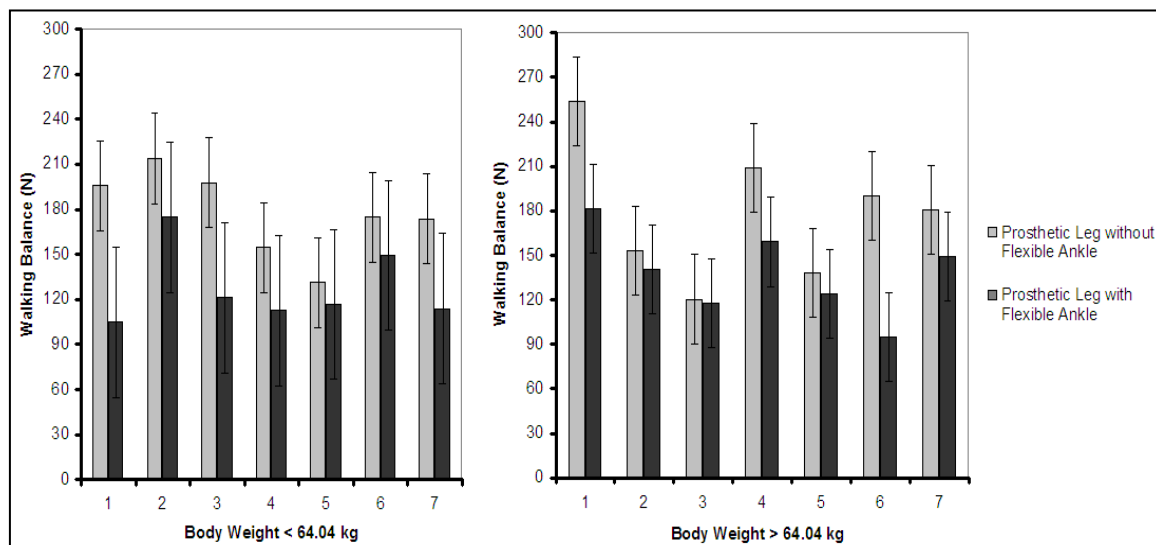


Figure 2. Walking balance towards body weight during gait used to both prosthetic foots.

The results of ANOVA enabled the parameters to be classified. Walking balance parameter is mostly dependant on prosthetic foots type. The walking balance parameters of the amputated side are influenced by prosthetic foot type. The average prosthetic foot used by amputees is different. It was noted that walking balance and amputated step length is greater for the group of subject equipped with flexible ankle system. Table 2 summarizes the results obtained from this group of parameters.

Table 2. Effect of body weight and prosthetic flexible ankle on walking balance during amputee gait.

Parameters	df	Mean Square	ANOVA <i>p</i> -values.
Corrected Model	3	4806.726	0.013
Intercept	1	675190.050	0.000
Body Weight	1	220.288	0.655
Prosthetic foot	1	14031.500	0.001
Body Weight * Prosthetic foot	1	168.389	0.696

- $R^2 = 0.358$ (Adjusted R Squared = 0.278)
- Dependent Variable: Walking balance (N)

The results of body weights no significant influence on the walking balance ($p > 0.05$), so the weight is more than 64.04 kg body weight did not differ with less than 64.04 kg during amputee gait. A significant difference is observed in the weighty body of the forefoot relative to hind foot according to prosthetic foot types. The prosthetic foot is a significant influence on the walking balance ($p < 0.05$), a significant difference for prosthetic foots without and with flexible ankles during amputation. The results of the relationship between body weight and prosthetic foot no significant effect on the walking balance ($p > 0.05$), so the effect of body weight on the walking balance does not depend on a prosthetic foot. Body weight affected both types of a prosthetic foot. The graph in Figure 3 explains the balance of walking using prosthetic foots for two different types.

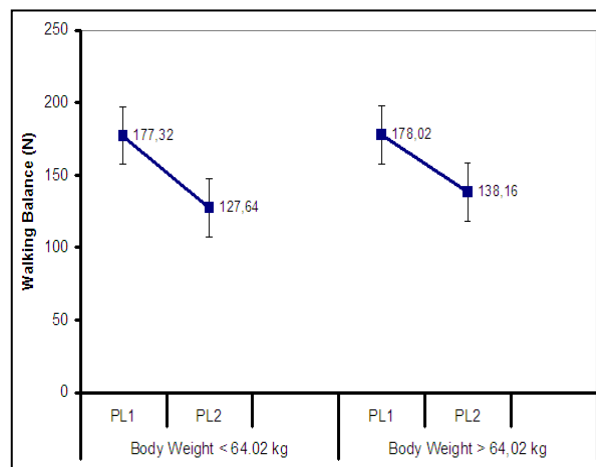


Figure 3. The walking balance on the bodyweight subject of the two types the prosthetic foot.

Correlations were searched for between weight body and the prosthetic foot without and with flexible ankle parameters and walking balance parameters, on the other hand. It was then conducted on subjects wearing flexible ankle-foot. This research was first of all conducted on amputees in order to determine if the kinetic characteristics of the two feet types of functionally on the overall gait are shown in Table 3.

Table 3. The results of Pearson correlation between walking balance and prosthetic feet.

Coefficient	Body Weight (kg)	Prosthetic feet
Pearson Correlation	0.074	-0.590**
Sig. (2-tailed)	0.708	0.001
n	28	28

**Correlation is significant at the 0.01 level (2-tailed)

Because the correlation coefficient with a negative result is -0,590 **, the two variables between walking balance and prosthetic foot have an inverse correlation. That is, if walking balances a high value, the value of the prosthetic foot will be low and vice versa. This explains the significant relationship between the two variables with a value of $0.001 < 0.01$, the correlation between walking balance and prosthetic feet is very strong, significant and overturned. A strong correlation on range of motion is found between the prosthetic foot with a flexible ankle and walking balance.

3.2. Discussions

This study aims to analyse the effect of weight and prosthetic feet without and with flexible ankle choices on gait amputations. Comparing their results, differences can be seen in the walking balance parameters, suggesting that gait patterns are significantly different between prosthetic foot without and with a flexible ankle. Comparing their results, differences in the parameters of walking balance that explain gait patterns differ significantly between prosthetic feet without and with flexible ankles. This condition is influenced by gait symmetry and direction of prosthetic footsteps. Previous studies

conducted gave descriptions for walking balance for the duration of stance phase [37-39]. The thrust in the prosthetic foot is also determined by the length of the stump. The results of this study when confirmed showed the same results with the results of the study of Goujon *et al.* 2006 which explains the thrust is influenced by walking patterns rather than by prosthetic feet [13], although they do not measure gait in transtibial amputations. Zmitrewicz *et al.* [5] explain the presence of prosthetic foot force due to cadence rather than prosthetic feet. This was explained by Zelik *et al.* [40] that the results of austerity explain there is no significant difference in the driving force of amputations that wear the feet. Foot movements are assumed to be very different for exoskeletal prosthetic feet without ankles compared to flexible ankle feet. Assessing accurate leg movements in the walking cycle, a testing protocol can be proposed in which the feet are as two rigid objects articulated as intact legs and prosthetic feet. Whereas previous studies were limited to the analysis of ankle movements, this work allowed the calculation of gait [40-43].

Moreover, the use of a foot device improves also the calculation of walking balance. The sagittal ankle range of motion appears to be not significantly dependant on foot type. This finding is in apparent contradiction with the results of previous studies which report an increased ankle range of motion with a flexible ankle [40, 41]. The design of endoskeletal prosthetic foot with flexible ankle obviously permits a large movement of the mid-part of the foot due to the spring flexibility [44]. It has been found on the results that the flexible ankle significantly more than the exoskeletal leg during the late stance phase. During gait, forces and moments are applied to the exoskeletal prosthetic foot because there is no structural element and depend on the cosmetic cover. The results of the correlation illustrate stiff legs on the SACH of the feet at flexible ankles. This condition provides the possibility of prolongation of prosthetic footsteps to prevent collapse in stance phase [13, 45]. Strong correlations are the two variables between walking balance and prosthetic feet which are less rigid-flexible ankles allowing better development of the whole body. The magnitude of the angle of flexion of the forefoot to the hind limb correlates with the magnitude of the anteroposterior strength.

4. Conclusions

This study explains the effect of prosthetic foot movements without and with flexible ankles on gait parameters. The propulsive force of the prosthetic foot is influenced by the amputee gait pattern rather than the type of prosthetic foot used. Flexible ankle movement is demonstrated by the increased dynamic displacement of the body during the mid-stance position and allows for reducing the peak of anteroposterior strength. Thus, flexible ankle behaviour can be known with certainty. The protocol related to body weight and evaluation of prosthetic feet with flexible ankles will help transtibial amputees to walk like normal people.

5. References

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