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Original Article

Gait Analysis of Ankle Joints of Indonesians at Low, Medium and High Speeds

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Abstract

Background : Amputation is a loss of body part, and most amputations are lower extremity amputations. The most common is transtibial amputation. After an amputation a person will need a prosthesis. However, up to now there has been no functional prosthesis specifically made for Indonesians who undergo transtibial amputation because the ankle joint gait data that are currently used are European gait data. So it is necessary to measure the normal gait data of Indonesians' ankle joint. The aims of this study was to measure the normal gait data of the ankle joint of Indonesian population
Methods : The Research sample is Indonesians aged 18–26 years with normal gait measured by the 2DMA (two-dimensional motion analyzers) at low, medium and high speeds. The resulting data is searched for the mean and standard deviations and then an independent t-test is performed between normal gait data of Indonesians and Europeans
Results : Indonesians have a range of maximum dorsiflexion values for low, medium, and high speeds of : 7.9°, 8.3°, 8.9° and maximum plantar flexion for low, medium, and high speeds of 13.4°, 20.6°, 26°. In the comparison test there was a significant difference between the maximum plantar flexion angle of Indonesians and Europeans.
Conclusion : Indonesians have a range of maximum dorsiflexion values for low, medium, and high speeds of 7.9°, 8.3°, 8.9° and maximum plantar flexion for low, medium, and high speeds of: 13.4°, 20.6°, 26°. There is a difference between the normal gait of the ankle joint of Indonesians and Europeans.

Keywords : Ankle joints; dorsiflexion; gait analysis; plantar flexion

INTRODUCTION

Amputations of all parts of the body, and 85% of amputation procedures are lower extremity amputations. Every year 150,000 people undergo lower extremity amputations in the United States. The most common lower extremity amputation is transtibial amputation / below knee amputation.[1,2] A 2019 cross sectional study in Malaysia involving 170 patients who had undergone surgical intervention for diabetic foot infections at three district hospital revealed that of 170, a total of 21 patients undergone major amputations of lower limbs (15 transtibial and 6 transfemoral).[3]

Transtibial/below knee amputation is an amputation that involves removal of the foot (pedis), ankle joint, distal tibia and fibula and surrounding tissue.[4] Ideally, within four to eight weeks, the limb stump is healed enough so that an amputee can go on to have a prosthesis with addition to limb physiotherapy. So mobility and prosthesis play a significant role in the rehabilitation of patients after undergoing transtibial amputation.[5] The ankle joint or articulatio talocrural is a joint formed from the lower part of the tibia and fibula bones with the upper part of the talus and its main motion is plantar-flexion and dorso-flexion.[6] The ankle joint connects the crus with the pedis, thereby enabling a kinetic connection between the lower extremities and the ground, which is a prerequisite for the formation of a gait cycle or cycle of walking and other activities of daily living.

Gait can be assessed and compared from one person to another using gait analysis. Gait analysis is a set of procedures that function to observe, measure, interpret and analyse how to move.[7,8] Deviations in gait, especially those involving the ankle joint can affect the walking cycle and cause certain compensation.[9]

There are several approaches to gait analysis such as vision-based (including direct using markers such as three-dimensional motion analysis, and non-direct/without markers), sensor based (using Ground Reaction Force Plates, electromyography), a combination of the two, and approaches using tools. such as an electrogoniometer.[10] Gait analysis is performed by observing joint movement and then comparing it with certain gait parameters. One of the parameters used is the kinematic parameter. This parameter assesses changes in body segments regardless of the forces acting. One example of the kinematic parameters being assessed is the change in the degree of angle at each joint followed during a walking cycle.[11] The data obtained is then used to determine the range of motion in the prosthesis to be made.

However, currently there has been no functional prosthesis made spesifically for Indonesians after undergoing transtibial/below knee amputation due to the normal ankle joint gait data currently used are European gait data. Previous study comparing the gait of different races (African American's and White American's) shown that there are differences in kinematics parameter between the two, including ankle joint kinematics.[12] Currently, there are no database of ankle joint kinematics of Indonesians. Racially, and by leg length, weight and height between Indonesians and Europeans are different, so it is suspected that it can affect the results of gait analysis, including the ankle joint. The reference data for normal ankle joint gait at various speeds are expected to be a reference for the manufacturer of a prosthesis that can approach a physiological gait for Indonesians after undergoing transtibial/below knee amputation.

METHODS

This study took place at UNDIP CBIOM3S Laboratory, Semarang, Indonesia. The subjects were Indonesian people aged 18–26 years with normal gait qualitatively with observations in the city of Semarang and has been approved by Health Research Ethics Committee Diponegoro University (No. 215/EC/KEPK/FK-UNDIP/VI/2021). The study subjects that were involved in this study needed to meet inclusion criteria such as: a qualitatively normal gait of vision which was carried out by one orthopaedic specialist and one general practitioner. Gait is normal, indicated by a regular and symmetrical gait cycle without any additional movement and without any complications in complex gait maneuvers such as stopping, turning around, jumping on one or two legs and walking backwards; have a complete number of limbs; can walk on a treadmill smoothly; willing to be a research subject and follow research procedures; Indonesian people aged 18–26 years who do not have a mixture of genes from outside Indonesia; not currently suffering from illness characterized by fever and fatigue/malaise. Subjects who have a walking disorder and difficulty; have a history of head trauma that causes neurological symptoms; have had lower limb surgery; have experienced trauma that causes changes in the form or function of the lower limbs were excluded. This age group was chosen because in this age category no degenerative changes related to aging are present, and this age group express mature gait, with less variability compared to children.[13,14] Study sampling by simple random method, with Confidence Interval 95% and absolute error value of 10%, the sample size of this study was 44 subjects which were divided into 22 males and 22 females. The research sample used leggings and socks and then was given a marker in the form of coloured paper at the ankle joint (*malleolus lateralis, metatarsal lateralis* and superior and parallel to the *malleolus lateralis*) as shown in Figure 1. The markers are affixed to the right foot outside. Figure 2 presented the method with which the gait assessment is done.

Figure 1. Marker Placement

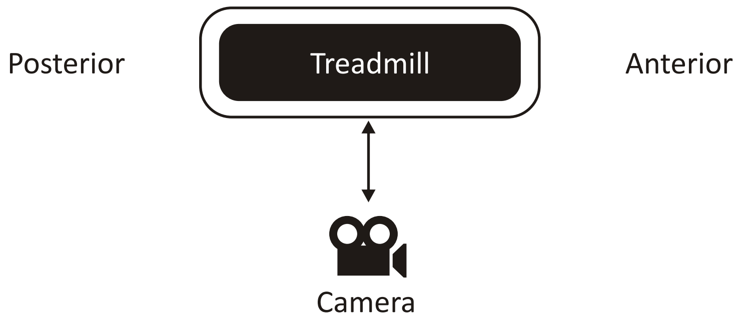

Figure 2. Camera placement

The study sample walked on a treadmill at low, medium, and high speeds for 10 phases of walking for each speed. The different speeds were used on this research because different walking speeds affect the ankle kinematics.[14] The walking will be recorded using 1 camera located on the right side of the treadmill. The point 0° when the ankle joint was in the anatomical position, formed an angle of 90° and was perpendicular to the plane. In this study, point 0° was determined by measuring the anatomical position using software and then averaged over the entire sample. (Software measurement produces raw data which must be reduced by the value of 0). Of the 10 moving phases at each speed, the angle of the ten running phases was assessed, then the average value and standard deviation were sought.

The kinematic parameters were tested using an unpaired T test to determine the comparison between the reference standard of normal gait of the ankle joint of Europeans with data obtained from the gait of Indonesians being studied. Pearson's correlation analysis was performed for leg length relationship to ankle joint angle size and body mass index relationship to ankle joint angle size. Spearman correlation test was performed for walking speeds relationship to ankle joint angle size.

RESULTS

Research subjects had an average body mass index of 22.22 ± 4.74 kg/m^2, average leg length 86.95 ± 4.90 cm and average height 164.23 ± 8.39 cm. Subject characteristic are shown in Table 1.

At low speed, male subjects had a maximum dorsiflexion angle of 5.86 ± 4.41° and a maximum plantar flexion of 14.81 ± 5.26°. Female subjects had a maximum dorsiflexion angle of 10.09 ± 4.27° and a maximum plantar flexion of 12.02 ± 5.22°. There is a significant difference in the maximum plantar flexion angle between research subjects compared to European literature studies on male subjects (p<0.001) and female subjects (p<0.001) (Table 2).

At medium speed, male subjects had a maximum dorsiflexion angle of 5.37 ± 3.47° and a maximum plantar flexion of 21.88 ± 7.83°. Female subjects had a maximum dorsiflexion angle of 11.28 ± 4.72° and a maximum plantar flexion of 19.41 ± 8.21°. There is a significant difference in the maximum plantar flexion angle between research subjects compared to European literature studies on male subjects (p=0.026) and female subjects (p=0.018) (Table 2).

At high speed, male subjects had a maximum dorsiflexion angle of 6.44 ± 3.13° and a maximum plantar flexion of 25.33 ± 7.40°. Female subjects had a maximum

TABLE 1
Characteristics of the study subjects

Variable		Mean ± SD	Median (Min – Max)
Gender	Male n=22 (50%)	–	–
	Female n=22 (50%)	–	–
BMI (kg/m^2)		22.221 ± 4.744	20.9 (15.8 – 36.1)
Leg length (cm)		86.95 ± 4.904	87 (77 – 100)
Height (cm)		164.23 ± 8.397	165 (140 – 182)

TABLE 2
Ankle joint angle analysis subjects

Ankle Joint Analysis at Different Speeds	Literature	Male	Female	*p*-value - male	*p*-value - female
Maximum dorsiflexion, LS	8.2°	5.864° ± 4.412°	10.098° ± 4.278°	0.612	0.669
Maximum plantar flexion, LS	38.6°	14.810° ± 5.267°	12.025° ± 5.222°	0.000	0.000
Maximum dorsiflexion, MS	9.1°	5.372° ± 3.470°	11.285° ± 4.727°	0.305	0.656
Maximum plantar flexion, MS	41.0°	21.885° ± 7.803°	19.415° ± 8.216°	0.026	0.018
Maximum dorsiflexion, HS	10.8°	6.448° ± 3.134°	11.310° ± 4.387°	0.189	0.910
Maximum plantar flexion, HS	45.0°	25.335 ° ± 7.403°	26.720° ± 7.787°	0.017	0.032
Gender Relationship to Ankle Joint Angle Size		**Male**	**Female**	***p*-value**	
Maximum dorsiflexion		5.405° ± 3.472°	11.285° ± 4.727°	0.000	
Maximum plantar flexion		21.885° ± 7.803°	19.415° ± 8.216°	0.313	

LS ; Low Speed, MS ; Medium Speed, HS ; High Speed

dorsiflexion angle of 11.31 ± 4.38° and a maximum plantar flexion of 26.72 ± 7.78°. There is a significant difference in the maximum plantar flexion angle between research subjects compared to European literature studies on male subjects (p=0.017) and female subjects (p=0.032) (Table 2).

There was a significant difference between the maximum dorsiflexion angle between men and women (p<0.001) but there was no significant difference in the maximum plantar flexion angle (Table 2).

Based on the relationship analysis, it was found that walking speed had a connection with the maximum plantar flexion angle (p<0.001) with a unidirectional relationship and moderate correlation strength (r=0.592) (Table 3). There is a connection between leg length and the maximum dorsiflexion angle (p=0.034) with the opposite relationship and the strength of the weak correlation (r= -0.321) (Table 3). However, there is no connection between body mass index and the maximum dorsiflexion angle and maximum plantar flexion (Table 3).

DISCUSSION

The purpose of this study is to provide a reference of normal gait data of Indonesian people and to investigate whether racial diffrences exist in kinematics gait analysis. The knowledge of kinematics data of the ankle joint, is one of the fundamentals for making a prosthesis for the lower limb. Espescially ankle-foot prosthesis.[15] Knowing the difference between kinematics data of Indonesians and Europeans will provide a better functional prosthesis made specifically for Indonesians. A 2017 systematic review of 12 studies found that walking with a prosthesis was the most notable factor that influenced quality of life of people who underwent lower extremity amputation.[5] Kinematics data provided can also be utilize to aid gait

TABLE 3
Different factors relations to the ankle joint angle size

Walking Speeds	Correlation Coefficient	*p*-value
Maximum dorsiflexion	0.074	0.397
Low Speed		
Medium Speed		
High Speed		
Maximum plantar flexion	0.592	0.000
Low Speed		
Medium Speed		
High Speed		
Leg length		
Maximum dorsiflexion	-0.321	0.034
Maximum plantar flexion	0.060	0.699
Body mass Index		
Maximum dorsiflexion	-0.097	0.530
Maximum plantar flexion	0.148	0.339

analysis done by clinician with providing an objective data, and thus helping the clinician to assess patient's gait. The normal gait range of the Indonesians' ankle angle during maximum dorsiflexion is 7.9°, 8.3° and 8.9° at low, medium, and high speeds. At maximum plantar flexion, the ankle angles were 13.4°, 20.6° and 26° at low, medium, and high speeds.

At maximum dorsiflexion angle, whether at low, medium, or high speeds, there was no significant difference between the ankle joint of Indonesians and Europeans. But at the maximum plantar flexion angle, at low, medium and high speeds there were significant diffrences between the two groups. The mechanisms for these diffrences remain untested, perhaps we can suggest that due to the range of motion of ankle joint during dorsiflexion are smaller than when performing plantar flexion.[6] This can provide a “similar” comparison between the two groups. And for the plantar flexion angle which shows significant diffrences between the two groups might be because the ankle joint has a greater range of motion during plantar flexion compared to when performing dorsiflexion movements. Apart from that Europeans need a greater maximal plantar flexion to propel a body with greater mass than of Indonesians.

In male and female subjects, a significant difference was found in the maximum dorsiflexion angle, in which the dorsiflexion of female subjects is greater than that of male subjects. This finding is in line with several previous studies that yielded the same conclusion, where female subjects had larger angles than men at the same speed. This happens because to travel the same speed as male subjects, it takes more effort.[16]

Based on research data, leg length affects the movement of the ankle joint. Especially at the maximum dorsiflexion angle where a significant and opposite relationship is obtained, which means that the longer a person's leg length, the smaller the maximum dorsiflexion angle will be. This can be explained based on previous studies that assessed the relationship between height and the length of one gait cycle (leg length is a component that plays a role in determining a person's height). Several previous studies have stated that the longer the leg length of a person, the faster the gait cycle will be.[17,18] The faster gait cycle will certainly lead to a narrowing of the gait phases, including the terminal stance phase, the phase where the ankle joint reaches its maximum dorsiflexion angle.[11] Before the ankle joint can reach the maximum dorsiflexion angle, due to the rapid phase the ankle joint is ready to perform a swing phase to push the body forward before reaching the maximum dorsiflexion angle. The method in which the gait analysis is done in three different speeds hopefully can provide a more “real-world” data. In which in our daily life, we do not walk at the same constant speed. And speed influence the gait kinematics of ankle joint, like what is proven in this study, and also previous studies.[14,19,20] Thus ensuring the data can be utilized to produce a prosthesis that can be used at different speeds is important.

This study has several limitations first, the camera used are limited to 60 fps video recording. While the use of this camera can represent the data, the use of 120 fps camera will reduce the blur effect thus providing more data to the motion analyzer, and preventing re-recording due to blurry video quality in certain frames. Second, this study only compares walking in a flat and smooth surface, while in the real-world situation, a person might walk in an ascending descending surfaces and also uneven surface.

CONCLUSION

There is a difference between the normal gait of the ankle joint of Indonesians and Europeans at low, medium, and high speeds. Especially at the maximum plantar flexion angle which shows a significant difference. The higher the walking speed, the greater the maximum plantar flexion angle. The longer, the length of a person's limbs, the smaller the maximum dorsiflexion angle. Gender affects ankle joint gait, especially at the maximum dorsiflexion angle where female subjects have a greater maximum dorsiflexion angle than male subjects.

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