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COMPARISON OF ENERGY COST IN TRANSFEMORAL PROSTHESIS USERS USING MECHANICAL FOUR-BAR LINKAGE AND PNEUMATIC SYSTEM PROSTHETIC KNEE JOINTS

Diah Nuraliah Rahmi[1], Jusuf Kristianto[1], Agusni Karma[1]
[1]Prosthetics and Orthotics Department, Poltekkes Kemenkes Jakarta, Indonesia

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Abstract

Background. The prosthetic knee joint is an essential component of the transfemoral prosthesis. Different types of knee joints are used in transfemoral prosthesis. The different features found in artificial knee joints affecting on different energy costs to prosthesis user during walking. The selection of prosthetic knee joints should be appropriate to the user's needs. **Research purposes.** To analyze and comparing two types of prosthetic knee joint four bar linkage mechanical and pneumatic system in minimize the energy cost during walking. **Research methods.** Quantitative descriptive. The participants were 4 men transfemoral prosthesis user. Energy cost calculation is done with five minutes walking test, which is participants observed for 5 minutes by using prosthetic knee joint four bar linkages mechanical and pneumatic system. **Results.** The results showed that the prosthetic knee joint fourbar linkage pneumatic system decreased the energy cost by decreasing the value of PCI ($p < 0.05$) and the participants's speed was increase significantly affected ($p < 0.05$) compared to the fourbar linkage mechanical. **Conclusion.** The results show decreased PCI values and increased walking speed in the use of prosthetic knee joint fourbar linkage pneumatic system. It can be concluded that the use of pneumatic knee joints can clinically facilitate prosthesis users during walking.

Author Correspondence:
Diah Rahmi
Jl. H. Saleh No. 39, Pondok Labu – Cilandak
Email: dn.rahmi@gmail.com

Introduction

Amputation is the removal of one or more than one parts of the body in order to improve the health and quality of life of the prosthesis user (Demet et al. 2003). There are many types of amputation, and one of them is transfemoral amputation.

The prosthetic knee joint is one of the most important components of the transfemoral prosthesis to help the prosthesis user walk following normal person walks (Normal Gait). The prosthetic knee joint design is generally classified by the type of articulation they provide and the means of articulation control. Examples of this type of articulation are monocentric (single axis) and polycentric. While the meaning of the control means of articulation is prosthetic knee joint can provide control on the phase walking are divided into; Stance Phase Control and swing phase control (Highsmith et al. 2016).

The higher the level of amputation, the energy cost required for walking will be increase and reducing the walking speeds. So, during walking, transfemoral amputation level need higher energy cost compared to transtibial amputation level(Waters et al. 1976). With a prosthetic knee joint design that mimics the anatomical system of the human knee, it is expected to decrease the energy cost of the transfemoral prosthesis user. Restoring leg function to run by restoring knee function to energy efficiency in walking can help them in decreasing energy cost. The more efficient energy cost of transfemoral prosthesis users, the more it will help them in daily life (Ülger, Topuz, and Bayramlar 2009).

According to a normal gait, the stance phase period, there is a loading phase response, this phase is called the phase with the highest energy requirements compared to others in the normal phase of gait. In the phase of knee function is to absorb shocks that occur during walking. The knee provides the function of absorbing shocks with knee flexion motion. Flexion of the knee is the second largest mechanism to absorb shocks when walking. But in this phase position of gravity line (ground reaction force) is behind the knee joint, creating big knee flexion moment. And if the prosthesis user cannot resist or control these moments then the knee will tend to collapse or fall. Therefore, the users of the transfemoral prosthesis will extend the knee to control and stabilize the knee while walking or they will lock the knee to provide the stability. And at the period of swing phase. According to normal gait, in that period there is a degree of flexion on the knee that makes it shorter in order to smoothly move forward. And in prosthesis users who lock the prosthetic knee joints, there will be problems for clearance, they will compensate when walking in the swing phase by pushing the prosthesis out half-circle (circumduction), or they do other compensation when walking in the swing phase, such as pelvic lift (hip hiking), vaulting in contralateral limb, and doing lateral flexion of the body (lateral trunk bending). All compensation is done so that the prosthesis user can get clearance in swing phase period, because at the time they walk they cannot make the knee joint prosthetic to be flexed at the period of swing phase (Fitzsimons 2012).

The effectiveness of Prosthetic Knee Joint can be assessed from energy cost when transfemoral prosthesis users walk with prosthesis. Energy cost can affect prosthesis users' mobilization in their daily activities. If the amount of energy cost is large, it will make prosthesis users get tired easily while doing daily activities (Andrysek et al. 2011). The absence of knee joint function at walking time can increase energy cost during walking. And using prosthetic knee joints such as mechanical four bar linkage or four bar linkages with additional features can reduce the energy cost of transfemoral prosthesis users while walking (Bernardi et al. 1999).One method of energy cost calculation is direct measurement for oxygen consumption (VO2), but it is not generally available in clinical practice, due to the equipment needed during the measurement. Physiological Cost Index (PCI) was first introduced by McGregor as a method of linear correlation between VO2 and heart rate. This requires a record of the heart rate at rest and when walking and can be measured with inexpensive equipment. Measuring PCI has been becoming the subject of many publications for prosthesis users with movement abnormalities and also for prosthesis users

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with amputation who are walking on prosthesis (Nene 1993).

This study is very important in the field of prosthetic orthotic science to determine the consumption energy of different prosthetic knee joint usage, and to know which knee joint is more efficient for walking in subject to energy cost for transfemoral prosthesis user. And in this research the hypothesis is energy cost on transfemoral prosthesis users during walking will be smaller and PCI numbers closer to numbers of PCI normal people when using prosthetic knee joint with pneumatic system compared to mechanical four bar linkage prosthetic knee joint.

Materials and Methods

This study will test two different types of knee joints by testing the Physiological Cost Index when a participant walks using each of the knee joints. The type of research used is comparative quantitative by calculating the average Physiological Cost Index on each different prosthetic knee joints. The comparison method is used to compare participants' average outcomes when walking with prosthesis with different prosthetic knee joints.

A five-minute walk test was performed. Energy cost was calculated by applying a five minutes walking test to participant using the two prosthetic knee joint and was expressed as Physiological Cost Index (PCI) (beats/min) [(walking heart rate) - (resting heart rate)/ (walking speed (m/min)]. The participants were asked to rest on a chair for at least 10 minutes before the start of the test. Resting heart rate of the participants were measured. Then, participant was instructed to stand up and walk and was reminded not to run or jog. As soon as the participant started to walk the timer was set. With the sound of the timer the participant stopped walking and was allowed to sit on a chair. Heart rate and blood pressure were measured again. The walking distance was recorded. After the 5-minute walking test, comfortable walking speed (CWS) was calculated for the PCI.

The mean PCI value for healthy adults is between 0.23 and 0.42. And the walking speed of healthy people in comfortable conditions (comfortable walking speed), has been reported between 60 to 100 m / min (Nene 1993).

The data were analyzed by testing the hypothesis using statistical data processing software program in the form of bivariate analysis to know the comparison of two different types of prosthetic knee joints. The statistical test used is an Independent T-test to see the comparison between two different prosthetic knee joint variables with probability values (p-value = 0.05) and with a 95% reliable level. And Chi-Square is used to analyzing the correlation of the type mechanism of prosthetic knee joint is used in reducing the energy cost.

Results

After the Physiological Cost Index was tested using two types of prosthetic knee joint mechanical four bar linkage and pneumatic system at the Prosthetic Orthotics Laboratory of Poltekkes Jakarta I in February-May 2018 with the number of respondents 4 (four) participants. And the following is the characteristic demographics of respondents based on age, height and percentage of residual limb are shown in table 1.

Table 1. Demographic Characteristic of Participant

	Min-Max	X±SD
Age (years)	28-58	42.0±15.2
Height (cm)	155-162	159.5±3.3
Residual Limb (%)	25-90	57.5±28.4

The results of the Physiological cost index obtained from the 5-minute walking test were lower when the subject used a prosthetic knee joint four bar linkage pneumatic system. In conclusion, energy costs are lower when using a pneumatic system than when a prosthetic knee joint mechanical four bar linkage is used ($p < 0.05$) (Table 2).

PCI					
Variables	**N**	**Mean**	**SD**	**SE**	**P-*value***
Mechanical	72	0,330	0,117	0,0196	0.000
Pneumatic Sys.	72	0,199	0,199	0,108	0,000

Table 2. Result of Means Comparative Test (T-test) of Energy cost using Mechanical Fourbar Linkages and Pneumatic System

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Increased walking speed and distance amount obtained from a 5-minute walking test, when subjects used a prosthetic knee joint four bar linkage pneumatic system. In addition, energy costs were lower than when using a prosthetic knee joint mechanical four bar linkage ($p < 0.05$) (Table 3).

Table 3. Result of Means Comparative Test (T-test) of Walking Speeds using Mechanical Fourbar Linkages and Pneumatic System

WALKING SPEEDS					
Variables	**N**	**Mean**	**SD**	**SE**	**P-*value***
Mechanical	72	0,812	0,598	0,010	0.000
Pneumatic Sys.	72	0,971	0,118	0,011	

Interviews results from 4-participant satisfaction says that they prefer to walk using a prosthetic knee joint four bar linkage pneumatic system, with the reason that the prosthetic knee joint is more stable during walking, and can better control for walking speed, thus the participant feels safer to walk compared to prosthetic knee joint mechanical four bar linkage.

In table 4 shows the results of the Chi square test on both types of prosthetic knee joint value p = 0.000. The result of the analysis of the relationship between the use of both types of knee joint by decreasing the energy cost is obtained that 56 (77,8%) energy cost of prosthetic knee joint pneumatic system user is well decreased. Meanwhile, between the use of mechanical four bars, there are 22 (30.6%) whose energy costs are well decreased. From result of analysis also obtained value of OR = 7,955.

Table 4. Chi Square Test Result for Two Types of Prosthetic Knee Joints

Type of Knee Joint	**Decreasing Energy Cost Category**				Total		**OR (95% CI)**	***P-value***
	Well		**Deficient**					
	N	**%**	**N**	**%**	**N**	**%**		
Mechanical	22	30.6	50	69.4	72	100	7.955	0,0
Pneumatic	56	77.8	16	22.2	72	100		
Total	78	54.2	66	45.8	144	100		

Discussion

Many publications have dealt with energy costs in the use of prosthetic knee joints in the literature, but almost all of the studies found comparing four bar linkages of prosthetic knee joint mechanical and hydraulic. This study is important from the point of view of determining energy cost in comparing the two different prosthetic knee-joint four bar linkage that is the type of mechanical and pneumatic system of most literatures which more often discuss about hydraulic prosthetic knee joint. Therefore, the author will make the literature that discusses it as a reference, because the type of prosthetic knee joint hydraulic and pneumatic have the same in the mechanism which is the application of hydraulic system. This study is important from another perspective determining the energy cost in comparing the two different prosthetic knee-joint four bar linkage that is the type of mechanical and pneumatic system, different from the literature most often discuss the hydraulic prosthetic knee joint.

Robert L. Waters, Rae, Jacquelin, & Richard (1988) stated that prosthetic ambulation is a major concern in the rehabilitation process of lower limb amputations, and this is primarily aimed at energy cost and speed of walking. The importance of this is correlated with other measures of prosthetic ambulation (Waters et al. 1988).

Measuring energy cost in amputation of the lower limbs is mostly done by the method of measuring oxygen consumption (VO2), but for clinical setting, measuring energy cost is more suited to the PCI (physiological cost index) measure. The only equipment required is a standard heart rate monitor and stopwatch.

Energy consumption is usually measured with a floor test (the test that is done on the floor) or treadmill test but the author chose the floor test because of the ability of participant to choose the most comfortable walking speed (comfortable walking speed). Based on Bernardi et al., (1999) walking speed is considered a reliable measure of the highly correlated as other aspects of walking (Bernardi et al. 1999).

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In this study the average PCI value for mechanical four bar linkage was 0.330 (SD = 0.117) and for the average PCI value the pneumatic system was 0.199 (SD = 0.199). In this study the use of pneumatic system succeeded in decreasing energy cost during walking.

The results of this study are in line with the results of the experiment by Blumentritt, Scherer, & Wellershaus (1997), especially in terms of walking speed, it has been obtained in trials of gait performed using a prosthetic knee joint pneumatic. And also in line with the results of research by Ülger et al., (2009) (Blumentritt, Slegmar; Scherer, Hans Werner; Wellershaws, Ulf; Michael 1997).

In this study energy cost is calculated using PCI. Subjects used less energy when they walked for five minutes using a transfemoral prosthesis with a pneumatic knee joint. It is estimated that the lower PCI obtained in this study with pneumatic knee joints due to the easy adaptation of this component, has a wider range of motion than the mechanical knee (mechanical four bar) joints in the current phase. The subjects stated that pneumatic knee joints were quite similar to normal knee joints when they walked pneumatically for five minutes. They do not feel tired during walking, they feel like an original limb. The PCI values reflect this situation and the results are positive for the pneumatic knee joint.

Table 4 shows the results of the Chi square test of both prosthetic knee joints. The result of analysis of the relationship between the use of both types of knee joint by decreasing the energy cost obtained that there are 56 (77.8%) users of pneumatic system whose energy cost decreased well.
Meanwhile, between the use of mechanical four bars, there are 22 (30.6%) whose energy costs are well decreased. The result of statistic test obtained p value = 0,000 hence can be concluded there is difference of proportion of incident of decreasing of energy cost well between mechanical four bar and pneumatic system four bar (there is significant relation between usage of prosthetic knee joint type with decreasing energy cost). From the analysis results also obtained the value OR = 7,955, meaning the use of prosthetic knee joint pneumatic system has a chance of 7.95 times to reduce energy cost compared to the use of mechanical four bar.

Conclusion

Based on the results of this study can be concluded that Prosthetic knee joint four bar linkage pneumatic system is closer to normal energy cost compared to prosthetic knee joint mechanical four bar linkages. Transfemoral prosthesis users have significant differences in physiological cost index, walking speed, and distance when using prosthetic knee joint mechanical four bar linkages and prosthetic knee joint four bar linkage pneumatic system. The use of a prosthetic knee joint four bar pneumatic linkage system has the possibility to reduce energy costs 7.95 times in reducing energy costs in a participant of transfemoral prosthesis user when walking.

In conclusion, the authors assume that the results of the authors are parallel to the relevant literature and can stimulate interest in conducting further studies in the field of prosthetics. The authors think that the authors' research that proves that the selection of appropriate prosthetic components has a positive effect on energy cost and can outline a framework for further guidelines designed to describe prosthetic prescriptions for both personal and government insurance systems in Indonesia.

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