

FOUR SUSPENSIONS FOR TRANSTIBIAL PROSTHETICS: A Case-Study

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Abstract

Objectives - The harmony between the residual limb and the prosthesis with an effective and comfortable suspension system allows the amputee to fully continue their daily living activities. With this study authors intended to measure gait efficiency and conclude whether the suspension systems tested differ in the various transtibial prostheses, based on the data provided by indirect calorimetry.

Methodology - Functional performance that each suspension system allows will be approached by analyzing quantitative variables such as gait efficiency through indirect calorimetry using Lin-Chan protocols, which uses 5 different treadmill speeds.

Results - Gait efficiency analysis of the four suspension systems (2 suction; 1 PIN; 1 VASS) showed that when comparing the four models, the most functional suspension system was the prosthesis with the active vacuum suspension system (VASS) with lower values for mlO₂/kg/m and higher distance than other suspension systems.

Conclusion - Differences in results of the tests carried out in the various suspension systems prove that indirect calorimetry is sensitive in the assessment of the identified variables and is a viable tool in the analysis of gait efficiency in amputees, proving that the VASS suspension system is what presents a greater efficiency in walking and so a higher functionality.

*Suspension, Gait efficiency;
Functional performance*

Introduction

The human being is designed to be energetically efficient during ambulation. The greatest expenditure of energy during walking is reduced to muscular consumption to allow the Mass Center (MC) to move with a minimum vertical and horizontal displacement associated with a stable balance of the muscular system^{[1],[2]}. Any muscular or skeletal pathology creates interferences in this alignment / balance, forcing an increase of muscle work with a higher energy consumption^[2].

Human gait, up to present, has no equivalent in machines built by man in terms of mechanical efficiency (ME) when walking, with an average of 25% of energy being converted to work and the remaining 75% in heat^[3]. Gait is, compared to all other human movements, the most effective movement in terms of ME^[3].

Since century XIX, Zuntz and Hagemann, are able to rigorously quantify the metabolic values of the body, both for nutritional and clinical / diagnostic purposes, through the techniques of direct calorimetry (determination of the heat produced by the catabolism of lipids and carbohydrates) and indirect calorimetry (calculation of heat produced, but measured by volume of oxygen consumed (VO₂) and volume of carbon dioxide (VCO₂) produced^[4,5]. Determination of gait efficiency by measuring energy expenditure is an ordinary method of functional evaluation in professional practice^[6,7].

An adult human male, in a comfortable gait, walks in average 110 steps per minute, with the average speed reaching 4.8 km/h, requiring 4 Kcal/min to raise the center of gravity. This represents 90% of the energy expenditure of the gait and the remaining 10% is responsible for acceleration and deceleration^{[1],[8]}.

Each person has as maximum mechanical efficiency strategy, a comfortable walking speed (CWS) that is self-selected for spontaneous walking. This type of gait presents for the general population the speed of 82m/min in men, and of 74 m/min in women^[6,7], translating into an average O₂ consumption of 12ml/kg/min, with an average heart rate of 99 beats per minute (bpm) and with an energy cost of 0.15 ml/kg/m, equivalent to about 50% of the

maximum consumption of O₂ (VO_{2max})^[3]. The concept of gait efficiency was defined according to Lin-Chan^[9], as the ratio between the consumption of O₂ and the distance travelled according to the following equation^[9]:

$$\frac{\text{VO}_2 \text{ ml/Kg/min}}{\text{m/min}} = \text{ml/kg/m}$$

The value of the gait energy cost or gait efficiency, by presenting each time lower values will correspond to an increasing gait efficiency^[7,9]. For speeds below CWS, the power consumption will be less per unit time, and its efficiency will be reduced. On the other way, when using an higher speed the energy consumption will be higher per unit of time and distance travelled, the efficiency will be also lower^[3].

Thorstensson and Roberthson^[6] have defined that the transition point between walking and running will occur at 113m / min, i.e. running is more efficient than walking from that speed.

In individuals with amputations frequently present changes in three components of ME in gait: changes in the musculoskeletal system (change in joint levers), neural control of movement (alteration of remaining muscles) and/or metabolic energy production systems (eg. reduction of aerobic capacity due to immobilization)^[3,7]. In vascular amputees, there may still be a limitation on O₂ transportation. Individuals with peripheral neuropathies showed difficulty in controlling the prosthesis, which contributes to an increase in energy expenditure^[3]. As a strategy to reduce this energy consumption individuals with lower limb amputation reduce the speed of CWS^[3,10], in order to maintain heart rate (HR) around 100 bpm, which is the value of HR in CWS to obtain O₂ consumption close to normal gait, but with lower running efficiency^[3].

In patients with amputation from vascular etiology, energy expenditure is higher than that of patients amputated by traumatic or neoplastic etiology, due to the existence of either central (hypertensive or ischemic cardiopathy with reduction of cardiac output) or peripheral conditions (diffuse atherosclerosis, diabetic microangiopathy, with reduction of O₂ extraction by the muscle fiber)^[3].

In these cases, CWS for unilateral transtibial amputees of vascular etiology appears to be on average of 45m / min, with an O₂ efficiency or cost of 0.26 ml / kg / m^[3,7]. Several authors have concluded that transtibial amputees spend about 20% more energy than non-amputees^[1,6,11-15].

Waters (1976)^[16] concluded that amputees of vascular etiology walk at a CWS of 45 ± 9m/min, while amputees by traumatic etiology walk at a CWS of 71 ± 10m/min which corresponds to a reduction in velocity between the two groups of 37%. The cost of O₂ was 0.26 ± 0.05 ml/kg/m, in amputees by vascular etiology and an O₂ cost of approximately 0.20 ± 0.05 ml/kg/m in amputees by traumatic etiology. Traballese^[17] reports also that amputation by vascular etiology implies higher oxygen consumption values than those presented by amputees of traumatic etiology. The purpose of this study was to understand which of the different types of suspension of transtibial prosthetics presents greater energy efficiency in gait in transtibial amputees, when assessing it using direct calorimetry.

Materials and methods

Methodology

This case study analysed a 22-year-old male, 170 cm, 71 kg, with a congenital anomaly, Q68.4103, Q73.1103 and Q72.3103, treated. As a result of this congenital anomaly, a right and unilateral transtibial amputation was made resulting in a 14cm stump, conical in shape with 19 cm of perimeter (4 cm at the distal level). Patient presented an higher level of activity corresponding to K3^[18,19], without associated pathologies. Subject was selected because he had no experience of use of any kind of transtibial prosthesis in the last year, walking with the help of crutches. This fact is of extreme importance due to non-exposure to any of the variables under study, namely the different types of suspension used in transtibial prosthesis.

Four different suspension models were tested in 4 different moments to analyze gait efficiency with each of the different models.

Procedures were previously explained to the subject under study, as well as the sequence of the same and the care to be taken, having obtained the proper written informed consent in accordance with the Declaration of Helsinki.

Efficiency of gait

For the analysis of the energy cost of gait or gait efficiency, the protocol used by Lin-Chan^[9] and Hsu^[20] was used. This protocol use a treadmill running test without inclination, resorting to five levels of successively increasing speeds: 53.64; 67.05; 80.46; 93.87 and 107.28 m/min, that is, respectively 3.2184 km/h; 4.0230km/h; 4.8276km/h; 5.6322km/h and 6.4368km/h performed on a treadmill H/P Mercury H/P Cosmos® with a protocol lasting 4 minutes each level.

Gas collection was made by expired breath-by-breath analysis, using Quark PFT Ergo Cosmed® equipment during the treadmill walking, yielding VO₂ values of the last level using walking averages of 15 seconds.

Laboratory conditions were monitored at a constant temperature within the neutral zone (25° to 26°)^[4].

Data were collected on the same day of the week, at the same time, with a period of 4 weeks of adaptation between each of the prostheses with the same conditions between each test. Participant was advised to keep the same habits in the 24 hours prior to the tests, same type of meal, without previous intake of coffee, shoes were identical and comfortable clothing in the different moments of assessment.

Before the start of the test and before the start of the first stage, there was a period of adaptation of participant to the equipment and to the treadmill running, with a duration of 5 minutes. During this period CWS was found.

At the end of each step blood pressure was measured, respecting the maximum values of systolic blood pressure (BP) of 250mmHg or diastolic BP of 115mmHg as criteria for test interruption^[21].

At the end of the test, the participant was also asked to identify the level of intensity of perceived exertion in Borg's (6-20) Subjective Rate of Perceived Effort Scale. It was established as a safety threshold to complete the test, the HR corresponding to 90% of the estimated maximum heart rate found by equation:

$$HR_{\max} = 220 - \text{age in years}^{[22]}$$

Gait efficiency (ml / kg / m) was calculated by the ratio between oxygen consumption (ml/kg/min) and walking speed (at the last level) (m/min)^[20]. According to this study, the lower the value of this ratio, the better the gait efficiency.

Results

Results obtained with the different suspension types are shown in Table 1. The stopping criterion of 90% of the estimated maximum HR was the reason for the end of each of the four tests.

According to results, at the end of each test all suspension types demonstrated an efficiency of 0.20. In spite of this, suspension by VASS, was the one that allowed greater distance covered (1102 meters) or more walking time / use of the prosthesis (15.30 minutes). Thus, this will be the suspension considered as enabling a greater efficiency of walking with greater distance travelled with obvious repercussions on the functionality and independence of this participant in particular.

Suspension by PIN (suspension B) was the suspension that allowed less time of use / prosthesis use (10.3 minutes) and shorter distance (712 meters).

Rate of perceived exertion at the end of each test was for each of the types of suspension referred to as 13.

Table 1. Results obtained in variables of oxygen consumption (VO_2), gait efficiency and distance on 6 minutes walk test for different types of suspension or prosthesis, according different gait efficiency and distance walked the different types of suspension systems, according to the different levels reached.

		<i>Suspension A (hypobaric membrane)</i>		<i>Suspension B (PIN)</i>		<i>Suspension C (suction by knee brace)</i>		<i>Suspension D (VASS)</i>		
<i>Speed (m/min)</i>	<i>Time (min)</i>	<i>VO₂ (ml/min/kg)</i>	<i>Efficiency (ml/kg/m)</i>	<i>VO₂ (ml/min/kg)</i>	<i>Efficiency (ml/kg/m)</i>	<i>VO₂ (ml/min/kg)</i>	<i>Efficiency (ml/kg/m)</i>	<i>VO₂ (ml/min/kg)</i>	<i>Efficiency (ml/kg/m)</i>	<i>Distance walked (m)</i>
0	0	4,84	---	8,08	---	7,69	---	8,07	---	---
53,64	0-4	14,34	0,27	11,68	0,30	14,65	0,26	14,37	0,27	211
67,05	4-8	15,00	0,22	16,04	0,18	14,45	0,22	17,19	0,26	478
80,46	8-10,3	----	---	16,18	0,20	---	---	---	---	712
80,46	8-12	17,15	0,20	---	---	17,58	0,21	18,61	0,23	799
93,87	12-12,45	---	---	---	---	18,64	0,20	---	---	882
93,87	12-13,3	18,71	0,20	---	---	---	---	---	---	939
93,87	12-15,30	---	---	---	---	---	---	18,46	0,20	1102

Discussion

According to Waters^[23], the CWS for a transtibial amputee by traumatic etiology is located in 71 ± 10 m/min which will match a O_2 consumption of $15.5 \pm 2, 9$ ml/Kg/min and a cost of 0.20 ± 0.05 ml/Kg/m. This value according to several authors^[1,6,11-15] corresponds to an increase of about 20% energy compared to "no amputees". In our study, the speed of 71 ± 10 m/min, is between the other protocol speeds of 67.05 m/min and 80.46 m/min where it was obtained the VO_2 max values between 12.26ml/Kg/min and 18.61ml/Kg/min and a cost (efficiency) between 0.18 ml/Kg/m and 0.22ml/Kg/m, showing that the data from this study is generally in accordance with other studies^[3,23,24].

The reasons for the efficiency values obtained in this study for the different types of suspension, are related with characteristics of prosthetic suspension system D (VASS). Suspension of prosthesis is obtained by the expulsion of the molecules of air between the liner and the socket via a pump, which creates a set of suction forces of 78 KPa, equivalent to the need of the application of a reverse traction force of 70 kg needed to separate the liner from the socket^[24-27].

Applying this suspension system based on vacuum supply during the swing phase of gait shifts fluids to the residual limb, improving the fit of the prosthesis by strengthening the link between the socket and the stump^[27], avoiding volume changes^[28], incrementing the proprioception^[24,26,29] and comfort, increasing the daily functionality^[24,28,30].

Possible explanations of how the suspension VASS improves the volume of stump, is that less interstitial fluid is expelled from the residual limb due to a reduction in positive pressure during the phase of full contact and due to an increase in negative pressure during swing phase (27% higher, when compared with the same stage in the suspension system with suction) displacing more interstitial fluid to the stump^[25,31].

In this suction suspension movement of the liquid is in the opposite direction^[24]. The stump with the suspension system with suction loses 6.5% of the volume, whereas with the suspension by VASS he could increase 3.7% of the volume^[24,27,28], going on 95% of this amendment in the first two hours^[24].

In the swing phase there is an increase of 27% of the negative pressure in the swing phase, compared with suction suspension system, this is due to the fact that there is an "anchor point" between the interface and the socket and the interface and the stump, allowing a lengthening of the tissues that make up the stump, allowing that there is a decrease of pressure, much larger than other models of suspension^[25,31].

With the suspension system with suction valve the set liner/stump tends to detach itself from the socket, thus resulting in less tissue elongation and consequently a lower pressure drop and a smaller shift of interstitial fluid to the stump^[26].

The effect caused by the suspension by VASS and also by suction suspension, but on a smaller scale, appears to increase overall circulation by increasing the exchange of interstitial fluid, not promoting congestion unlike PIN suspension^[31].

Conclusion

The results seem to show that the suspension system D (suspension by VASS) is the one that allows greater functionality to the subject of this study.


This case study shows the importance of proper prosthesis to each patient, showing that the best suspension will allow better patient functionality. To identify the best type of suspension, i.e. the type of prosthesis best suited to the subject, the study of gait efficiency proved to be extremely useful and important, and so the use of this methodology in clinical practice.

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