RESEARCH ARTICLE

Energy Expenditure and Gait Parameters in Bilateral Transtibial Prostheses Users With and Without Sleeve Suspension: A Pilot Study

Priya Gajendiran[1], Bobeena R Chandy[2], Joyce Isaac[3], Bijesh Yadav[4], Rajdeep Ojha[5]

Abstract

Objective: To compare the energy expenditure and gait parameters of bilateral transtibial prostheses user with and without sleeve suspension.

Materials and methods: Five (4 male, 1 female) bilateral transtibial, patellar tendon bearing supracondylar (PTB-SC) prostheses users, 2 years postamputation, having good residual limbs and muscle power, were recruited in the study. Instrumented gait analysis, physiological cost index (PCI), timed up and go test (TUG), cadence and subjective feedback questionnaire were recorded on day 1 (without sleeve suspension) and day 15 (with sleeve suspension). Sleeve suspension was added with the prostheses on day 1. Adequate gait training for two weeks was provided to the participants. Wilcoxon signed-rank test was performed in SPSS 25.0 to compare the data recorded on days 1 and 15. *p* value less than 0.05 was considered as significant.

Results: The *p* values of various gait parameters walking speed, percentage of stance, swing, single limb support and normalized stride length, cadence and TUG test were found to be not significant while *p* value of step width and physiological cost index was considered significant. All the five subjects have reported comfort in ambulation after wearing sleeve suspension.

Conclusion: The study reports the effect of PTB-SC sleeve suspension in improving gait parameters and energy expenditure in five bilateral below knee amputee. Statistically significant improvement was reported in the cost of energy consumption and step width, suggesting that good prosthetic fitment is essential. However, the change in other gait parameters such as walking speed, percentage of stance, swing, single limb support, and stride length remained within normative data range. There is a need to conduct the study in a larger cohort with bilateral amputation where the essential component in prosthesis fitment, like sleeve suspension, can be varied, which in turn can give better stability and comfort resulting in improvement in walking efficiency.

Keywords: Bilateral transtibial amputee, Energy expenditure, Gait parameters, Sleeve suspension.

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Introduction

Efficient energy expenditure in human locomotion is achieved by smooth transition between the limbs during forward progression. This synergy between the limbs is lost in many neurological and orthopedic conditions such as amputation, polio, cerebral palsy, etc. The epidemiological data from the developed countries have ranked peripheral vascular disease as a major reason for amputation[1] while in India, peripheral vascular disease is preceded by diabetes and road traffic accidents.[2]

Rehabilitation in bilateral prosthesis users offers a great challenge not only to the rehabilitation team but also to the person with amputation.[3] A proper gait training in bilateral lower limb amputees depends upon several factors such as type, weight, and fitment of the prostheses along with balance, stability, and strength of the residual and upper limb strength and coordination of the patient. Loss of proprioception due to the amputation further adds to the difficulty. For the challenge of gait training and achieving independence, the amputee has to circumvent emotional and psychological barriers and should consider aforementioned factors to achieve energy efficient walking. It has been reported that the physiological cost of walking with bilateral prostheses is greater than with a unilateral prosthesis.[4–6] Su et al. have reported that bilateral prosthesis users have lower walking speed and cadences, shorter step length, larger step width and reduced ankle and knee moments than normal persons.[5] Studies have revealed that the bilateral transtibial amputees spend 40–125% more energy than the normal individuals.[7–9] This physiological cost of energy consumption is associated with the walking efficiency. There are number of causes which alter the walking pattern in bilateral lower limb prosthetic users such as pistoning, vaulting, alignment, etc. The improper fit of the prosthetic socket and failure of the suspension system can result in pistoning, which in turn affects the walking pattern.[10] A patellar tendon bearing supracondylar (PTB-SC) suspension is the good socket design for unilateral and bilateral transtibial amputees that minimizes the pistoning.[11] The advantage of this suspension is that it gives greater mediolateral

[1–3,5]Department of Physical Medicine and Rehabilitation, Christian Medical College, Vellore, Tamil Nadu, India

[4]Department of Biostatistics, Christian Medical College, Vellore, Tamil Nadu, India

Corresponding Author: Bobeena R Chandy, Department of Physical Medicine and Rehabilitation, Christian Medical College, Vellore, Tamil Nadu, India, Phone: +91 416-228-2158, e-mail: bobeenachandy@cmcvellore.ac.in.

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stability than the patellar tendon bearing suspension.[12] Amputees are known to use sleeve suspension for recreational and sports activities as this provides an excellent auxiliary suspension.[11] Though researchers have emphasized on the importance of sleeve suspension, most of the reported studies use subjective information as the primary outcome measure and do not report its effect on energy consumption. Hence, this study was designed to compare the energy expenditure and gait parameters of bilateral transtibial prostheses user with and without sleeve suspension, and to relate these effects to make the prescription criteria more explicit.

Materials and Methods

Eleven bilateral transtibial amputee ambulant with prosthetic limb fitted with patellar tendon bearing supracondylar (PTB-SC) prosthesis, 2 years postamputation, having good residual limb and upper limb muscle power were screened for the study. Of the eleven patients, six patients were excluded due to associated health issues such as cardiac insufficiency, hypertension, other vascular diseases, skin allergy, and hand muscle weakness. Informed consent was obtained prior to enrolment to the study. The subjects' existing prosthesis was assessed for pistoning on day 1 of the recruitment. In patients with more than the acceptable pistoning in the socket, standard methods were used to minimize the issue. Baseline timed up and go test (TUG) and instrumental gait analysis was done on day 1. Gait analysis was done at the Movement Analysis Laboratory, Department of Physical Medicine and Rehabilitation, Christian Medical College, Vellore, Tamil Nadu, India. Fifteen active markers from PhaseSpace motion capture system were placed at the level of bony prominence—metatarsal heads (both left and right sides), lateral malleoli (both left and right sides), heads of fibula (both left and right sides), lateral femoral condyles (both left and right side), greater trochanters (both left and right sides), anterior superior iliac spine (both left and right sides) and one marker was placed over the coccygeal bone of the subject. Gait parameters such as kinematics, stance swing ratio, walking speed, stride length, step length, and cadence were recorded at the time of data collection at self-selected speed. Physiological cost index (PCI) was derived by accessing the ratio of difference in postexercise heart rate and resting heart rate to the walking speed. Heart rate was recorded using biopotential amplifier placed in the lead II configuration, while walking speed was calculated using phase space motion capture system. The resting heart rate of the subject was obtained in supine position, and the postexercise heart rate subject was recorded during the final lapse of 25-m walkway inside the laboratory. Subjective feedback was taken from the participants about the comfort level of the existing prosthesis on day 1. After the completion of baseline data collection on the day 1, each subject was given the sleeve suspension (Fig. 1). Adequate gait training was provided to the subject for two weeks in order to acclimatize to the new sleeve suspension. At the end of two weeks, instrumental gait analysis, TUG test, physiological cost index and subjective feedback about the comfort level of prosthesis with sleeve suspension were repeated. Wilcoxon signed-rank test was used for statistical analysis of pre- and postquantitative data (i.e., without and with sleeve suspension). The p value less than 0.05 was considered as significant. Statistical analysis was done using SPSS v 25.0 by the statistician involved in the project. Informed consent was obtained prior to the enrolment to the study. The study was approved by the Institutional Review Board and Ethics Committee, Christian Medical College, Vellore, Tamil Nadu, India.

Fig. 1: Patellar tendon bearing supracondylar prosthesis with sleeve suspension

Results

Five patients (4 male, 1 female) out of eleven patients with bilateral transtibial amputees ambulant with prosthetic limb fitted with patellar tendon bearing (PTB-SC) met the inclusion exclusion criteria for the study. The demographic details of the participants are shown in Table 1. The participants had mean age of 43.4 ± 8.79 (range 31–54) years, mean height of 164.8 ± 10.8 (range 149–175), and mean weight of 66.75 ± 12.5 (range 53–83) kg. Of five subjects, two patients had amputation due to road traffic accident, two had amputation due to train accident while one patient had amputation due to diabetes and Hansen's disease. The duration of prosthesis use was more than 2 years (between 2 and 5 years (1 patient), between 5 and 10 years (1 patient), and between 10 and 20 years (3 patients)). The four male subjects were gainfully employed, and the female subject was homemaker.

Table 1: Baseline demographic data for the recruited subjects

Baseline demographic data	*Total (n = 5)*
Male (proportion)	4 (80%)
Female (proportion)	1 (20%)
Age (years) mean ± SD (median)	43.4 ± 8.79 (45)
Height (cm) mean ± SD (median)	164.8 ± 10.8 (163)
Weight (kg) mean ± SD (median)	62.2 ± 14.86 (63)
Duration of prosthetic usage	
Between 2 and 5 year	1 (20%)
Between 5 and 10 year	1 (20%)
Between 10 and 20 year	3 (60 %)
Cause of amputation	
Road traffic accident	2 (40%)
Train accident	2 (40%)
Diabetes and Hansen's disease	1 (20%)
Vocation	
Homemaker (proportion)	1 (20%)
Company job (proportion)	1 (20%)
Laborer (proportion)	1 (20%)
Security officer (proportion)	1 (20%)
Business (proportion)	1 (20%)

Table 2: Right (R) and left (L) side spatio-temporal gait parameters

Parameters	Amputation side	Mean ± SD		Median		Minimum		Maximum		p value
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	
Step width (cm)	–	10.4 ± 3.20	14.2 ± 3.03	10	14	7	10	15	18	0.043
Walking speed (m/minutes)	R	56.0 ± 11.02	59.6 ± 18.84	62	67	40	37	65	78	0.416
	L	55.8 ± 10.47	59.0 ± 18.48	59	66	40	37	66	79	0.500
Stance	R	63.0 ± 3.08	63.8 ± 3.56	64	62	59	61	67	69	0.317
	L	64.0 ± 1.41	64.4 ± 5.22	64	64	62	58	66	71	1.00
Swing	R	37.0 ± 3.08	36.2 ± 3.56	36	38	33	31	41	39	0.317
	L	36.0 ± 1.41	35.6 ± 5.22	36	36	34	29	38	42	1.00
% of single limb support	R	36.0 ± 1.41	35.6 ± 5.22	36	36	34	29	38	42	1.00
	L	37.0 ± 3.08	36.2 ± 3.56	36	38	33	31	41	39	0.300
Normalized stride length (with height)	R	0.78 ± 0.15	0.76 ± 0.20	0.77	0.78	0.55	0.48	0.96	0.96	0.686
	L	0.75 ± 0.13	0.77 ± 0.19	0.73	0.77	0.55	0.50	0.90	0.97	0.345

The spatio-temporal gait parameters for the left and right sides are shown in Table 2. Mean, standard deviation, median, minimum and maximum values of step width, walking speed, percentage of stance, swing, single limb support (SLS), and normalized stride length for both the limbs without (pre) and with (post) sleeve suspension are shown in Table 2. The *p* values of various gait parameters walking speed (right—0.416, left—0.5), percentage of stance (right—0.317, left—1.00), swing (right—0.317, left—1.00), single limb support (right—1.00, left—0.3), and normalized stride length (right—0.686, left—0.345) were found to be not significant while *p* value of step width (0.043) was considered significant.

The pre- and postintervention data for cadence, physiological cost index (PCI), and timed up and go (TUG) test are shown in Table 3. Mean, standard deviation, median, minimum and maximum values of cadence, PCI, and TUG test are shown in Table 3. The *p* values of cadence (1.00) and TUG test (0.59) were found to be insignificant while *p* value of PCI (0.043) was found to be significant.

The Figure 2 shows that PCI in all the five subjects have reduced after the sleeve suspension. There was no significant difference between gait kinematics curves. All the five subjects have reported comfort in ambulation after wearing sleeve suspension.

Discussion

Rehabilitation of patients with bilateral lower-limb amputation is more intensive because of the extent of the structural loss and the need to replace both limbs with prostheses.[3] The gait training in such prostheses users demands good trunk and upper-body strength, balance, muscle control, and proper prostheses fitment. Variation in any of these parameters can lead to high energy consumption.

Persons with bilateral transtibial amputations display bilateral hip hiking, which requires them to expend much more energy during gait compared with persons with unilateral amputations.[5]

The importance of a proper suspension system to ensure amputees' comfort and prosthetic function has been widely written in the literature. Vertical displacement of the residual limb or pistoning within the socket has been implicated to be one of the main indicators of suspension system efficacy in lower-limb prostheses.[13–15] A patellar tendon bearing supracondylar suspension is particularly used to minimize pistoning effect in unilateral and bilateral transtibial amputees. The main roles of the suspension systems incorporated into lower-limb prostheses are to hold the prosthesis on the residual limb and to decrease the motion that takes place at the bone-skin-liner-socket interface during ambulation like pistoning (vertical movements) within the socket.[13] The seal-in liner has been found to be the most effective suspension system in reducing the vertical movement during level walking in the study conducted by Gholizadeh et al.[16] Researchers have also studied the effects of prosthetic liner on the gait of transtibial amputees and revealed that liner thickness can affect the gait variables.[17] However, among various suspension systems for transtibial amputees, the Iceross system was favored by the majority of users in terms of function and comfort in the study conducted by Gholizadeh et al.[16]

The results of our pilot study shows no significant difference in walking speed, percentage of stance, swing, single limb support, and normalized stride length, indicating that the addition of sleeve suspension does not alter the walking pattern and stays within the normative range. The increase in the speed of walking with sleeve suspension can be attributed to the stability and comfort in walking.

We observed that the cost of energy consumption during walking with sleeve suspension has come down in all the five subjects. This suggests that the good fitting of the prosthesis is important and can reduce the energy consumption. This correlates with the study by Legro et al., which reports the fit of prosthesis and suspension as the most important factor in every prosthesis.[18]

With the addition of sleeve suspension, though the step width remained within the normative data range, however, the *p* value became significant. This increase in the step width indicates larger base of support and more stability. Further studies with regard to tracing the trajectory of center of mass of the body particularly, in bilateral amputees, would be helpful in correlating the improvement in step width.

Table 3: Pre- and postintervention data cadence, PCI, TUG test

Parameters	Mean ± SD		Median		Minimum		Maximum		p value
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
Cadence	94.8 ± 5.02	94.8 ± 6.57	96	90	90	90	102	102	1.00
PCI	0.72 ± 0.21	0.453 ± 0.18	0.82	0.54	0.44	0.32	0.96	0.74	0.043
TUG test	9.4 ± 1.57	9.6 ± 2.73	8.7	8.7	8.5	7	12.2	14.2	0.59

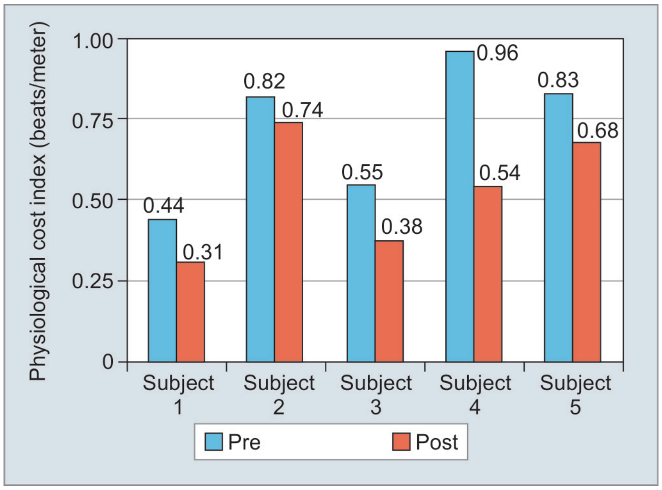

Fig. 2: PCI without (pre) and with (post) sleeve suspension in five subjects

Time up and go test and cadence continue to remain in normal range and unaltered with the intervention. TUG test is a time-efficient, cost-effective, safe, and reliable test to evaluate functional mobility in wide pathological conditions and has high relation to age.[19] However, the test is not sensitive for the small changes as in our study and also the five participants were age matched.

All the five participants, following the use of sleeve suspension, reported an increased level of comfort and security during ambulation by the subjective feedback questionnaire.

Conclusion

The study reports the effects of patellar tendon bearing supracondylar sleeve suspension in improving gait parameters and energy expenditure in five bilateral below knee amputee. Statistically significant improvement was reported in the cost of energy consumption and step width, suggesting that good prosthetic fitment is essential and that this can alter some of the gait parameters significantly. However, the change in other gait parameters such as walking speed, percentage of stance, swing, single limb support, and stride length remained within normative data range. There is a need to conduct the study in a larger cohort with bilateral amputation where the essential component in prosthesis fitment, like sleeve suspension, can be varied, which in turn can give better stability and comfort resulting in improvement in walking efficiency.

All the subjects reported better comfort with sleeve suspension, during ambulation based on the subjective feedback. In spite of no obvious, observable gait parameter change, the efficiency of ambulation improved significantly in the study participants with usage of the sleeve suspension. Therefore, this study indicates that the sleeve suspension can be recommended along with the prosthesis not primarily to improve the speed of walking, but to give comfort and the feeling of security while ambulating in patients with bilateral amputations, which in turn improve the efficiency.

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