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Original Article:

Energy Cost and Gait Efficiency of Below-Knee Amputee and Normal Subject with Similar Physical Parameters & Quality of Life: A Comparative Case Study

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Abstract:
The study focused on the comparative analysis of energy cost and gait efficiency between a below knee (BK) amputee and a reference subject (without amputation). It also attempted to indicate the specific feature responsible for a controlled gait with optimum energy cost for BK amputees. Selection criteria of the subjects were similar physical parameters and quality of life studied with WHOQOL-100 quality of life assessment. A Cosmed® k4 b2 Respiratory Analyzer system was used for the measurement of Oxygen Uptake (VO_2), Energy Expenditure per minute (EE) and Heart Rate (HR). Gait efficiency ($p < 0.0002$) was found higher for BK amputee than normal subject. The therapeutic activities and mainly walking rhythm contributed to improve the mobility & balance. This ensures the optimum time & co-ordination of movements and hence improves the gait efficiency for the BK amputee. Comparison with control group was performed to validate the data.
Key Words: Energy Cost; Gait Efficiency; Below knee amputee

Introduction:

The lower extremity amputees have to spend huge effort & time to achieve their lost gait efficiency. Achieving the efficient locomotion plays a major role in the individual development. (1) Ambulation is practically difficult in trans-tibial amputees. Excessive energy cost may be the cause behind that. Earlier studies have shown elevated relation of energy expenditure & decreased gait efficiency in the transtibial amputees in comparison to the normal subjects with non-pathological gait. (2-9) Gait efficiency is defined as energy cost per distance traveled in previous research papers. (15) The lowest value is considered the Optimum efficiency at the self selected speed. (2, 7) Previous research indicates the higher energy cost in amputees with leg prosthesis than normal at comparable walking velocities. (10-12) Ganguly et al discussed transtibial amputees consume 33% more energy than the normal subjects at 50 m/min walking speed. (3) In spite of this, most of those amputees achieved their normal gait within their limitation of disabilities. The physical parameters & Quality of life are the factors affecting the performance of the subjects. In this study, the subjects have been selected with similar physical parameters & similar Quality of life.

The purpose of this study was to compare the energy cost, gait efficiency of a physically active person with conventional BK Prosthesis versus a normal person with similar physical parameters (sex, age, height, and weight) & quality of life during their normal locomotion. The similar comparison was also done with reference to a control group for the data validation.

Methods:

One right trans-tibial amputee with conventional prosthesis with patella-tendon-bearing (PTB) socket & a solid-ankle-cushion-heel (SACH) foot for more than five years was selected in this study with his consent to the National Institute for the Orthopaedically Handicapped, Bon-hooghly, Kolkata-90, India. A normal subject participated as a reference with similarity in age, sex, height and weight data to the trans-tibial amputee.(Table-1) A control group was also selected with 30 normal subjects with non pathological gait.(Table 2) All the participants were physically active & well balanced to complete the protocol in full. The amputee was accustomed to wear the prosthesis and did not suffer from residual limb pain, swelling, or pressure sores. The fitting & alignment of the prosthesis was carried out by the resident Department of Prosthetics & Orthotics of the institute. The amputee was trained by therapeutic activities to improve the mobility with balance & to ensure the optimum time & co-ordination of movements. All the normal subjects were also examined & their fitness was certified. Subjects were asked not to ingest alcohol or caffeine for 24 hours prior to testing. A record of the subjects' diet was kept & a similar diet was maintained through out the study.

Table 1: Physical Parameters of the amputee and reference subject		
Criteria	**Bk(R) Amputee**	**Reference subject**
Sex	Male	Male
Age (yrs.)	45	46
Height (cm.)	162	163
Weight (kgs.)	61.5	62

Table 2: Physical Parameters of control group	
Criteria	**Average value**
Age (yrs.)	43±6
Height (cm.)	16.2±14.5
Weight (kgs.)	59.6±7.3

The subjects' Quality Of Life was studied with WHOQOL-100 quality of life assessment. The assessment would be applicable cross-culturally.(13) In this study the assessment indicates the similar Quality of life for both subjects. (Table 3)

Table 3: Quality of Life Assessment		
Domain	**Average Scores**	
	Subjects with BK Prosthesis	**Reference Subject**
Physical health	24.66	25
Psychological	19.18	18
Social relationship	10	11
Environment	27.7	27.5

The subjects were allowed to practice their usual gait prior to the testing until the normal gait pattern was observed. The subjects were instructed to walk at self selected speed. Through out this period, breath by breath analysis of the subjects was carried out. A Cosmed® K4 B2 Respiratory Analyzer system (COSMED Srl – Italy) at National Institute for the Orthopaedically Handicapped, Bon-hooghly, Kolkata-90, India was used for the measurement of Oxygen Uptake (VO_2), Energy Expenditure per minute (EE), Heart Rate (HR) for both subjects. (Figure 1)

Figure 1: Cosmed® K4 B2 Respiratory Analyzer system

The print out giving the subjects average VO_2 (ml/Min) over consecutive 60 seconds interval was processed by calculating the mean and standard deviation. A plane surface of 30 m was fixed for subjects' walking. The subjects were given sufficient time to become accustomed to the analyzer system before the experiments. Total test time was approximately 25 minutes consisting of a 3-minute warm-up period to ensure that the muscles did not utilize anaerobic sources of energy, 1 minute to prime the airways, and 1 minute of exhaled gas collection. The order of test configurations was maintained, and the consecutive information of the test was recorded at each condition. Fatigue was minimized by allowing subjects to rest during the intervals. Difference in VO_2 was determined for walking period of the subjects as follows:

$$\text{Difference in } VO_2 = \frac{VO_2 \text{ BK amputee} - VO_2 \text{ normal}}{VO_2 \text{ normal}} \times 100 \quad \text{(Equation-1)}$$

Thus a negative percentage would indicate energy saving and positive percentage would indicate higher energy cost for the subject with BK amputee.(14)

A more easily determined alternative criterion measure of gait efficiency is the term we refer to as "distance efficiency". Gait (distance) efficiency was calculated simply from the ratio of the oxygen uptake to the walking velocity and may be expressed in milliliters of oxygen consumed per kilogram of body weight per meter traveled.(15)

$$\text{Gait Efficiency} = \frac{mlO_2 / kg.min}{m/min} = mlO_2 / kg.min$$

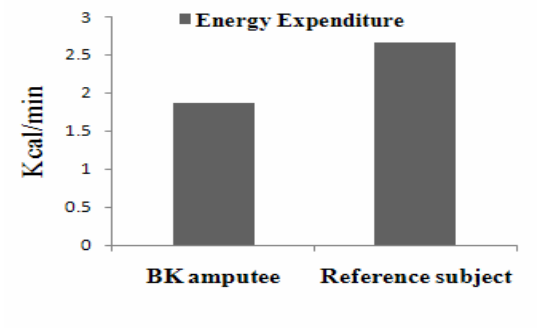
Statistics

Two-way analysis of variance (ANOVA) was used separately to test the level of significance of VO_2, HR, EE, velocity and gait efficiency & a level of $p < 0.05$ was adopted for the determination of statistical significance.

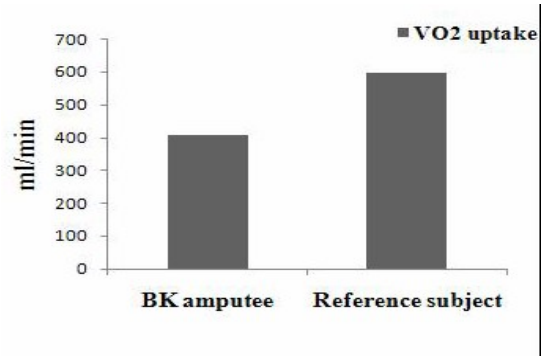
Results:

A summary of result is given in Table 4. Average Heart rate for BK amputee & reference subject was 87.92 ± 14.06 beats/min ($p < 0.002$) & 103.71 ± 7.80 beats/min($p < 0.0003$) respectively. The measurement of Heart Rate showed 12% more stability in the BK amputee. The velocity of the BK amputee & reference subject was 17.08 ± 1.48 m/min & 30.25 ± 3.59 m/min. Gait efficiency ($p < 0.0002$) is higher for the BK amputee (0.98± 0.10) than the reference subject (0.30± 0.26). The difference in VO_2 uptake for the amputee was -31.97%.

Table 4: Summary of result		
Parameter	**BK Amputee**	**Reference Subject**
VO_2 (ml/mint)	405.53± 264.99	596.096± 366.91
HR (beats/mint)	87.92± 14.06	103.71± 7.80
EE (kcal/mint)	1.87± 1.24	2.66± 1.72
Velocity (m/min)	17.08± 1.48	30.25± 3.59
Gait Efficiency (mlO_2 / kg . m)	0.98± 0.10	0.30± 0.26



Graph 1: Comparison of Oxygen Uptake



Graph 2: Comparison of Energy Expenditure

In comparison to the control group, the VO_2 uptake for BK were studied -16.26% whereas gait efficiency for the control group was found 0.29 ± 0.17 mlO_2 / kg . m.

Discussion:

The focus of the current study was to compare the Energy Cost & Gait Efficiency of BK- amputee with reference subject having the similar physical parameters & quality of life. Similar physical parameters allowed the subjects to be considered for comparison analysis. Both the subjects were found to lead similar Quality of Life. This indicates the nullification of any effect of the subjects' life style on their comparative performances. Thus the only difference between the subjects is due to the trans-tibial prosthesis of the BK amputee. The subjects were certified to be physically fit. The fitment & alignment of the prosthesis was checked & found perfect. The result obtained from Cosmed® $K4b^2$ showed consistency in heart rate monitoring for both the subjects. The subjects performed their normal gait during the test in their self selected velocity. The gait study advocated the normal gait pattern in both subjects through out the test. The energy expenditure for BK amputee & normal subject was 1.87 ± 1.24 Kcal/min & 2.66 ± 1.72 Kcal/min. The Energy expenditure of BK amputee was found 29.5% less with respect to the normal subject ($p < 0.0008$) & the difference in VO_2 uptake was -31.97% ($p < 0.0004$)(Equation-1). The negative percentage indicates energy saving for the BK amputee, which was not consistent with the previous paper.(10-12) The Gait efficiency was found ($p < 0.0002$) higher for the BK amputee (0.98 ± 0.10) than the normal subject (0.30 ± 0.26). In comparison to the control group the BK amputee showed negative percentage of VO_2 uptake & higher gait efficiency. This advocated the similar trend of data & validated the comparison between the amputee & the reference subject. This indicates that the BK amputee achieves a normal gait pattern under the limitation of disabilities. The result showed inconsistency with the previous published papers that the BK amputee was more efficient in Gait performance & less consumer of the energy in their usual & normal gait pattern. As most of the physical parameters were normalized by carefully selecting the test subjects after screening 50 numbers of patients and normal subjects, the walking rhythm played an important role to control the stability and increase the gait efficiency. This rhythm also contributed the uniformity of step time, step duration, cadence and stride length and helped the subject to achieve higher gait efficiency. The amputee achieved the gait rhythm & balance appropriate for his body mechanics by therapeutic practice. Improvement in time & co-ordination of movements ensured the efficient gait performance with reduced energy cost.(16) For this particular reason the BK amputee patient in this study was able to diminish his energy consumption compare to the normal subject for the identical performances.

The study will continue and additional research is recommended with more subjects to corroborate the findings of the current study.

Conclusions:

Appropriate time & co-ordination of movement resulted in confident gait rhythm & balance with less energy cost for the amputee in this study. Higher Gait efficiency & less Energy Expenditure were found for the BK amputee than the reference subjects with the similar physical parameters & quality of life for identical performances. This advocated that therapeutic practice & proper training for time & co-ordination of movements can help the amputee with below knee prosthesis to perform their ideal gait with less energy consumption.

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