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Original Article

# Relation of Stump Length with Various Gait Parameters in Trans-tibial Amputees

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**Abstract:**
The purpose of this paper is evaluating the impact of stump length of unilateral below knee amputees (BKA) on different gait parameters. Nine unilateral BKA were chosen and divided into three groups comprising patients with short, medium, and long stump length. Each of them underwent gait analysis test by Computer Dynography (CDG) system to measure the gait parameters. It was found that the ground reaction force is higher in the patients with medium stump length whereas the velocity, step length both for the prosthetic and sound limb and cadence were high in longer stump length. Statistical analysis shows a significant difference ($p<0.05$) between the gait parameters of BKA with medium and longer stump length. The patients with longer stump length were more efficient than medium and short stump patients as they consumed comparatively lesser energy while walking with self-selected velocity and conventional (Solid ankle cushioned heel) SACH foot.
**Key Words:** Stump length, Gait analysis, Trans-tibial amputee

## Introduction:

Optimal rehabilitation depends on good initial healing of the stump that also needs to be of the correct length and shape.[1] Incorrect stump length and stumps with excess tissue are significant and can have a permanent influence on the successful fitting of prosthesis.[1,2] In most of the studies, gait analysis was used as a tool for prosthesis design and also for a proper alignment to the prosthetic devices considering several important gait parameters.[3,4] But very few studies have focused about a comparison of gait variables and characteristics of the EMG signal among below-knee amputees with various stump length. The prosthetic component design, selection, and alignment of amputee's prosthesis are all directed towards obtaining optimal gait.[5] In this way the residual limb anatomy is a strongly considerable factor in ensuring successful rehabilitation.

A study revealed that in case of an amputation of lower limb, if the stump has sufficient length, a below-knee amputation has the best gait efficiency and prosthesis fit. If the stump is too short, a lengthening procedure may be beneficial.[6] In this study we showed that there were some differences in gait efficiency-regarding the velocity, energy consumption, and with different stride parameters in spite of using a well fitted prosthesis device. With a short trans-tibial amputation, the energy expenditure level increases by 40%, and by 10% if it is too long.[1,7]

In case of below-knee amputation, it was recommended that at least 8 cm below the tibial plateau be retained to allow optimal control of the socket and end-bearing.[8]

Physiological cost index (PCI) is a cardiopulmonary factor as an indicator of energy cost described by MacGregor, 1981.[9] In this study we investigated and quantified the difference in the gait parameters, electromyography characteristics of Vastus Lateralis muscle as well as PCI data among the patients with different stump length. Joan E. Sanders, [10] found that interface force between the socket and stump were highly sensitive to the stump length. Results from this analysis showed a more efficient gait with patients of longer stump length than the patients with medium and short stump length.

## Methodology:

Nine traumatic trans-tibial amputees were selected for this study purpose after scanning thirty six individuals with Transtibial amputation. A written consent, received from each of the subject, proves their spontaneous permission. The descriptive data of subjects were shown in Table-I. The subjects were confident to walk with the prosthesis, without any additional aid. None of them had any residual limb pain, sores, swelling and contracture etc. All subjects were fitted with conventional SACH foot.

The gait analysis system, Ultraflex Infotronic [11-14], was used for data collection. Pair of foot sensors called CDG (Computer Dynography) shoes was used to collect force distribution. Disposable surface EMG electrodes were used to record bilateral quadriceps (Vastus Lateralis) EMG. The foot sensor and EMG data were digitally acquired at a sampling frequency of 100 HZ and 1000HZ respectively and stored in portable data logger unit. The ECG system was used to record Heart Rate. The digitally collected EMG raw data were processed using MATLAB 7.0.

Gait analysis was performed with the self selected velocity of the subjects after a short trial period of free walking. Subjects (nine) were divided into three groups as per their stump length normalized with their Sound limb height: Group-I -patients with short stump length (range 18.9%-28.6% of sound limb); Group-II -patients with medium stump length (range 32.3%-38.3% of sound limb) and Group-III-patients with long stump length (range 54.2%-64.6% of sound limb).

An index was derived from the ratio of difference of active heart rate with rest to the velocity. This index reflects about the gait efficiency of the subject. Although the other research papers calculated the energy cost by oxygen uptake methods, the instruments are cumbersome, expensive, and not available in many clinics.[5] The statistical analysis was done by the help of statistical analysis software MS Excel. Analysis of variance (ANOVA) single factor test, paired T-test were used to analyze the data.

**Table 1: Group-wise descriptive data of the subjects**

| Parameters | Group-I (short) | Group-II (medium) | Group -III (long ) | Total (Group-I,II,III) |
|---|---|---|---|---|
| | Mean ± std | Mean ± std | Mean ± std | Mean ± std |
| **Age (year)** | 30.67±1.15 | 36± 11.53 | 24± 2.65 | 29.78± 8.45 |
| **Height (cm)** | 163± 14.8 | 159± 3.61 | 170.67± 2.31 | 164.22± 9.26 |
| **Weight (kg)** | 60.74±10.8 | 65.9± 3.92 | 65.21± 10.51 | 63.95± 8.15 |
| **Stump length as a % of Sound limb** | 23.71±4.84 | 34.77± 3.13 | 60.10± 5.30 | 39.53± 16.62 |
| **Prosthesis height (cm)** | 45.48±1.45 | 48.50± 1.32 | 47.67± 0.58 | 44.15± 8.89 |
| **Prosthesis weight (kg)** | 1.97± 0.50 | 1.71± 0.37 | 2.13± 0.36 | 1.94± 0.40 |

**Results:**

Various gait parameters were considered in all three groups of stump length comprising - short, medium and long stump amputees.

**Stump length and Energy index:**

Energy index of the subjects with long stump length was always less then the subjects with short and medium stump length, after a fixed work done. Walking in self selected velocity for a fixed time interval was the specific work here. The energy index decreased with the increment of stump length. A significant difference was found for this parameter as a result of statistical analysis.

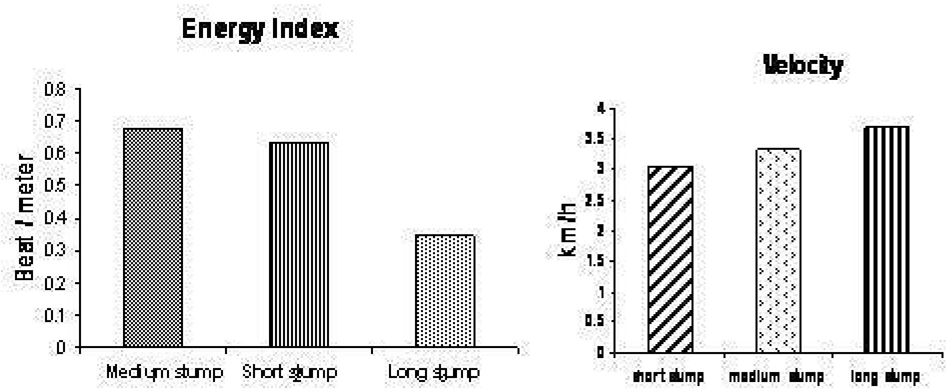


**Figure 1: relation of Energy index and velocity with stump Length**

**Stump length and velocity**:

Velocity was greater in case of the patients with longer stump length. It increased with increasing stump length, was supported by the difference in average cadence among three groups.

**Stump length and cadence**:

Correlation among cadence of three different groups was calculated that shows a significant difference with $p<0.025$. Cadence of the subjects was increased normally with increasing stump length.

**Table 2: Relation between velocity, cadence and stride length with stump length**

| Stump length as % of sound limb height | Velocity (K/h) | Cadence (steps/min) | Stride length (meter) |
|---|---|---|---|
| Group-I (18.9%-28.6% ) | 3.04± 1.14 | 90± 10.54 | 1.11± 0.32 |
| Group-II (32.3%-38.3%) | 3.34± 1.47 | 93.67± 15.18 | 1.17± 0.36 |
| Group-III (54.2%-64.6%) | 3.70± 0.74 | 108.67± 5.13 | 1.13± 0.19 |

**Stump length and step length:**

In a complete gait cycle, the distance from one heel contact to opposite heel contact is the step length. During normal gait, equal right and left step lengths are taken.[5] Considering different stump length, a significant difference in step length between sound and prosthetic limb was observed in case of short and medium stump length. The graph showed that Difference in step length between normal and prosthetic limb is shorter in case of patients with long stump length. Group-III-with long stump length had a significantly shorter sound limb step length; however group-II, comprising of patients with medium stump length had a significantly greater sound limb step length. But the statistical analysis shows that there is no significant difference in the step length of three different groups.

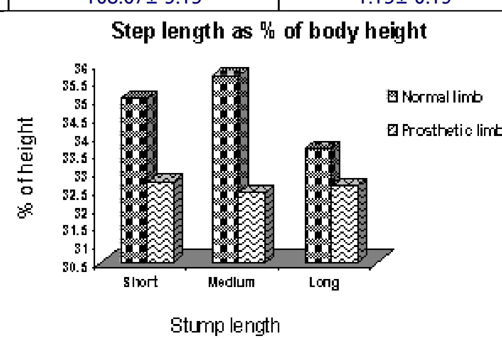


**Figure 2: Stump length and step length relationship**

**Stump length and Ground Reaction Force (GRF):**

Ground reaction forces at each instance of the stance phase were calculated as the percentage of body weight for normalization while walking at self selected speed with conventional SACH foot. GRF graph proved this fact that a greater peak vertical force in short stump length group was appeared in 80% than 20% of gait cycle. GRF pattern of long stump length patients showed a more similar 'M' shape curve with little bit greater impulse in push-off phase. This indicated a more energy storing gait in long stump length subjects.

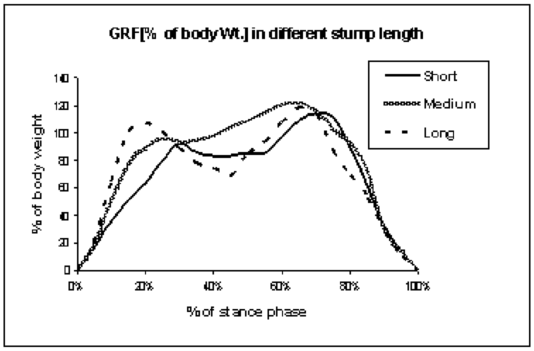


**Figure 3: GRF in different stump length for prosthetic limb**

**Stump length and Stride characteristics**:

A significant correlation was observed between Group-II and Group-III. Relatively the stride duration correlation coefficient between these two groups was 0.4483 ($p<0.02$). The P-value for stride duration within three groups was $p<0.03$ which indicated a significant difference among three groups.

**EMG and stump length:**

Normally over ground, the mean EMG peak of Vastus Lateralis (VL) activity at natural speed was in early stance. A second peak occurred in late swing in preparation for initial contact.[11] The data normalization was carried out by adopting the maximum mean value of each subject's EMG over the stride period as the reference value (100%).[16] Each stride was divided into 10% interval and average peak amplitude of ten strides for each subject was given a value 100% as adopted by Knutsson and Richards.[17] Each sub phase (10% of Gait Cycle) was expressed as a percentage of mean peak amplitude. The average value of amplitude expressed in percentage of Maximum Gait Contraction (MGC) was calculated for each 10% of gait cycle. The EMG pattern of the subjects of the all three groups had peaks in the 0 to 30% region of the gait cycle. These EMG patterns are almost similar in both legs. The only difference was the amplitudes higher in normal limb.

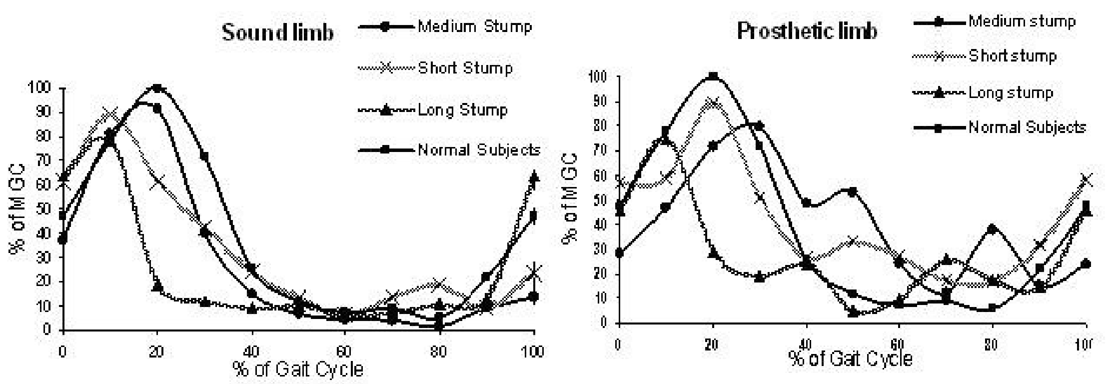


**Figure 4: Vastus lateralis EMG of the sound limb and amputee limb**

## Discussion:

A previous study had discussed that the successful rehabilitation of the amputee on a prosthetic limb depends on stump quality.[1] Thus, this study had only been confined to observe the impact of stump length on different gait parameters and EMG.

The result showed that the energy index reduced with the increasing the stump length, agrees with MERTENS P et al, 2001 and other works.[6,15-19]

The ideal mechanical advantage for a lever, like all other Simple machines is the length of effort arm divided by the length of resistance arm. According to this predicted theory below-knee amputees with longer stump length, where knee joint act as the fulcrum, have a resistance limb length longer than the effort limb length which co-operates to get a greater leverage arc. The greater leverage arc results a long step length. Where in case of short stump length patients the mechanical advantage is limited because of the shortening of resistance limb length.[20] It is obvious that a longer stump allows a better cantilever function in lifting the prosthesis, requiring less energy.[6] Whereas velocity increased linearly with the increase in length of the stump. This indicated the more degree of motion with longer stump.

Cadence of the individual group had a significant difference ($p<0.025$) and it increased with the increase in stump length. Similarly, stride length, step length also increased with the stump length augmentation whereas stride duration decreased.

Regarding Ground reaction force (GRF), it had been noted that during the heel strike more force were generated with longer stump length. It was observed that the heel strike force increased with the increase in stump length. Whereas, during the period of the Toe-off, on an average same force were generated. Here, the EMG study showed the same pattern in both the sound and prostheses limb, only mean amplitude increased with the increase in the stump length for the initial peak and decreased at the second peak. Initial peak indicated early phase of the stance. Strong muscle contraction occurred during early stance phase as stump length increased. The second peak during late swing depicted the preparation of next initial contact. Study showed that there were weak contractions during the above phase, indicated towards less energy consumption for longer stump length.

## Conclusions:

From our present study we could able to conclude that, in case of a below-knee amputation, gait parameters have a direct relationship with the stump length of the amputees. The amputee with a longer stump length (54.2%-64.6% of the sound limb length) performed more efficient gait in terms of less energy consumption, more velocity and more cadence respective to the shorter stump length patients. Moreover, in case of below-knee amputation, a longer amputation stump allows the use of a patella-tendon-bearing suction prosthesis instead of a thigh-bearing prosthesis, providing better skin protection and a more efficient gait.[21] Along with other parameters, stump length is one of the considerable parameter in gait efficiency and prosthesis fitting in case of trans-tibial amputee. Longer the stump length productive will be the prosthesis efficiency..


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