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Effect of Stump Length on Postural Steadiness During Quiet Stance in Unilateral Trans-Tibial Amputee

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Abstract: Although force platform based Center of pressure (COP) measures of postural steadiness have been used to test the diagnostic significance of various cerebellar and labyrinthine lesions, but very few literature are available on amputees. The aim of this work is to measure the effect of stump length of Trance-Tibial amputee on postural steadiness during quiet stance. The COP variation, which is the major determinant of stability, has been evaluated. Twenty transtibial amputee patients (age: 34±9.57 years) participated in this study. Among them, ten patients were having stump length of (19.33±2.04 cm) and ten patients were having stump length of (9.2±0.91 cm). Postural stability is evaluated considering following factors like, AP range, ML range, RMS distance, mean distance, sway velocity, sway area and mean power frequency. The result shows that the mean value of all the measure parameters are having higher values in case of patients having shorter stump length than there counterpart. Therefore, it is concluded that transtibial amputee with longer stump length has better postural steadiness.

Keywords: center of pressure (COP), stabilometry, postural sway, bipedalism, force plate, stump length.

Introduction

The postural steadiness is the dynamics of the postural control system associated with maintaining balance during quiet standing and usually assessed by the displacement of the center of pressure (COP). COP is the point where the resultant of all ground reaction forces act, in quiet standing and reflects the neuromuscular response to correct the displacement of the center of mass (COM) [1-4]. The direct method for monitoring the COP from the foot to ground reaction forces (GRFs) makes the trajectory of COP a widely adopted parameter to quantify human balance. The variation of COP not only integrates the information regarding postural steadiness, it also reflects the performance of lower extremities and the neuromuscular response to correct the position of the COM within the body [5]. The accurate estimation of the GRFs and COP can be done using a force sensitive platform when the subject stands on it. The force plate or stabilometer is an apparatus that can measure the force and its variation applied on it [6]. The parameters that are most commonly reported in the literature to determine postural steadiness are those that describe the statistical properties of the COP trajectory, considered as a stationary signal, in the time and frequency domains [7]. Many studies characterized postural steadiness with measures related to the velocity of the measured displacement [8-11], the area of the stabilogram [11-12], or the mean displacement of the COP [11,13]. Generally measure of postural steadiness evaluations include separate tests with eyes-open and eyes-closed. The ratio of the eyes closed to eyes-open measure, referred to as the Romberg quotient that estimate the impairment of the proprioceptive and vestibular systems by eliminating input from the visual system [8]. The control of posture is maintained by a complex sensory-motor system, which integrates information from the visual, proprioceptive, vestibular and somato-sensory systems [14-19]. Since the primary purpose of the lower limb amputee rehabilitation is safe and functional ambulation, postural instability has a negative effect on prosthetic rehabilitation. In the case of a unilateral trans tibial amputee, the individual becomes structurally asymmetrical, as there is an altered sensation and a loss of musculature on the amputated side. The identification and characterization of postural steadiness in different amputee factor may provide a better understanding of the static performance of the prosthesis rehabilitee system. During quiet standing, bilateral asymmetries in postural sway and weight distribution may occur in lower limb amputee with age, pathological, and type of prosthetic components, residual anatomy and prosthetic fitment, however residual anatomy or stump length in case of unilateral transtibial amputee has a significant role in prosthetic rehabilitation as indicated by Winter *et al* (1988) [20]. The objective of this study was to evaluate the impact of stump length on Prostheses - rehabilitee system by stabilometery, using time and frequency domain parameter of COP like ML-range, AP-range, sway area, mean distance, R.M.S distance, sway velocity and mean power frequency.

Materials and Methods

Subject Testing and Data Acquisition: In this study twenty unilateral Trans Tibial Amputees (TTAs) amputee patient of active groups of both sexes (34.25±9.57 years) were selected, having a minimum one year experience of using BK prosthesis (PTB socket and SACH foot) and , among them 10 patient having stump length getter than 15 cm (19.33±2.04 cm) and 10 patient having stump length less than 15 cm (9.2±0.91 cm).The subjects were selected through proper clinical assessment (to exclude other clinical conditions affecting stability before testing the stability.

Parameters	Short Stump (Group-I)	Medium Stump (Group-II)
	Mean ± Stdev	Mean ± Stdev
Age(Years)	30.67±1.15	36± 11.53
Height (cm)	163± 14.8	159± 3.61
Weight (Kg)	65.9± 3.92	60.74±10.8
Stump length(% of sound Limb length)	23.71±4.84	44.77± 3.13
Height of Prosthesis(cm)	45.48±1.45	48.50± 1.32
Weight of Prosthesis(kg)	1.97± 0.50	1.71± 0.37

A two load cell (strain gauge, Gauge factor-2, length-10mm, and resistanc-350 ohm) based unidirectional (vertical component of COP) force plate (top plate, 52X 52 X 17 cm, measured unloaded vertical natural frequency $f_{nat} \leq 260$ HZ) was used for stabilometric analysis [21]. The testing of the subjects was carried out in a fixed visual and acoustic environment (Figure-1) and the base of support was symmetric to central line or at 0, 0 coordinate. The toe out angle was fixed to 30 degree to central line. The distance between bases of feet was 6cm. A ramp slope was kept near the force plate for easy use by amputee. The amputee was asked to place his / her two feet on the affixed foot prints such that the central cross mark on the foot prints would be on the middle of his / her foot positioning. This was actually helped to place the subject's feet just over the central x- axis. The upper limb of amputee was advised to keep perfectly aligned on either side of the body. Special instruction was given to amputees to adopt a naturally straight posture and look straight ahead towards visual reference.

Figure-1: Fixed Visual Environmental set up

The output of the force plate filtered by low pass filter (cut off frequency 10Hz), was connected to data acquisition LAB JACK card [22] .The force plate data was digitally acquired at sampling frequency of 50Hz & processed in MATLAB 7'. The subject asked to stand on force platform as still as possible. In each subject, a two-minute test was used during each condition (eye open and eye closed). After testing firstly eye open condition then the subject was rested one minute then test eye closed condition. The last 70s (3500 data) was used to compute the time and frequency domain measure. Statistical methods (Pearson correlation coefficient, f-test and ANOVA) were used to check the significant different between each comparisons in MS-Excel. Probability level of $p \leq 0.05$ was accepted as indicative of a statistically significant difference in the individual comparisons

Computation of COP-Based Measures: In 1981, the International Society of Posturography suggested the use of two COP-based measures, mean velocity, and root mean square (RMS) distance, in their recommendations for standardizing force platform based evaluations of postural steadiness [23-24]. Time-domain distance parameters are associated with either the displacement of the COP from the central point of the stabilogram or velocity of the COP. COP is a bivariate distribution and include qualitative characterizations of the COP path in time-domain measures [25-26] , average distance from the geometric mean COP [27-28], root-mean-square distance from the geometric mean COP [18-19], mean velocity of the COP [23,31-32], total excursions of the COP, which is the total distance travelled by the COP

[23, 29-32], and range of the COP is the maximum distance between any two points on the COP path [24,31]. The area measures calculated on the COP path include cumulative circumscribed area [24, 33-34]. The COP path was defined by anterior-posterior (AP) and medial-lateral (ML) time series relative to the origin of the force plate coordinate system. The position of the mean COP on the force plate was defined by the arithmetic means of the AP and ML time series. Frequency-domain measures are generally calculated from the power spectral density, and include qualitative characterizations of spectral distribution of COP [35-36]. The mean power frequency in AP and ML direction was measured using Fast Fourier Transform (FFT). The frequency domain measures were selected for their ability to characterize the area or shape of the power spectral density. The power spectral density of the AP, ML, and RD time series was computed using the FFT.

Results

The COP trajectory showed an increased sway area in eye close condition compared to eye open in both group (Romberg ratio, 1.6 ±0.45 in medium and 1.7 ±0.46 in short stump). The COP measures only in eye open condition was discussed in this paper as all the measures in eye closed condition in both group were found similar alteration. The result of AP variation, ML variation and COP trajectory in eye open was depicted in Figure 2. Sway in the AP direction was found to be consistently greater than sway in the ML direction. The mean and standard deviation of both time and frequency domain COP measures of both group of stump length are shown in table-1. The sway area with medium stump length was found to be significant differ ($p<0.01$) from shorter stump length. Sway Area was more in shorter stump length. Similarly, figure 1.C explained that AP variation was more in short stump in comparison. The AP range in both group varied significantly ($p<0.001$), however no significant difference was traced in mean distance. Figure-3, indicated sway velocity decreased linearly with increased stump length. Mean velocity was also found less in medium stump length. The mean power frequency in AP direction was ten times more than ML direction.

Table 1 : COP Time & Frequency domain parameters

Parameters	**Shorter Stump (EO)**	**Medium Stump(EO)**	**P value (EO)**
ML Range(mm)	12.82 ± 4.41	10.17 ± 1.83	0.091
AP range(mm)	14.67 ± 2.67	9.87 ±1 .79	0.00055
R.M.S Distance (mm)	2.63 ±1.42	2.45 ±0.63	0.51
R.M.S Distance-ML (mm)	2.02 ±1.02	1.74±0.5	0.297
R.M.S Distance-AP (mm)	1.66 ±1.04	1.70 ±0.5	0.005
Mean Distance(mm)	2.32±1.23	2.16±0.56	0.381
Mean Distance-ML(mm)	1.67±0.82	1.42±0.42	0.2784
Mean Distance-AP(mm)	1.30±0.79	1.36±0.40	0.0025
Mean Velocity(mm/sec)	21.87±1.74	15.64±2.9	0.023
Mean Velocity ML(cm/minute)	15.75±1.99	14.51±1.87	0.224
Mean Velocity AP(cm/minute)	8.06±1.0	7.27±1.09	0.006
Sway Area(Square mm)	93.84±17.47	50.6±22.60	0.0017
Mean Power Frequency ML(Hz)	0.476±0.06	0.379±0.24	0.395
Mean Power Frequency AP (Hz)	0.417±0.07	0.310±0.09	0.039

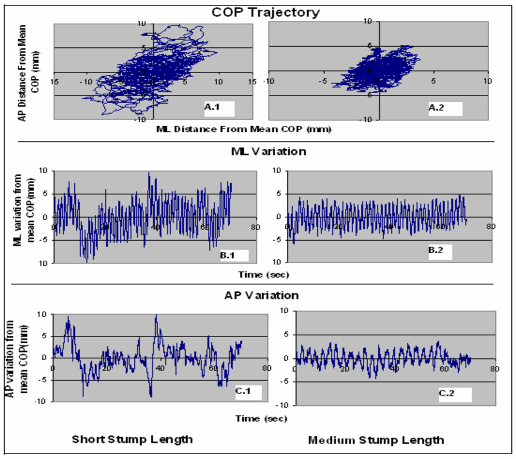

Figure 2: COP trajectory, AP variation, and ML variation of short and medium stump length BK amputee patient; fig: A1, fig: B1 and fig: C1 represent for short stump and figA2, fig: B2 fig: C2 represent for medium stump

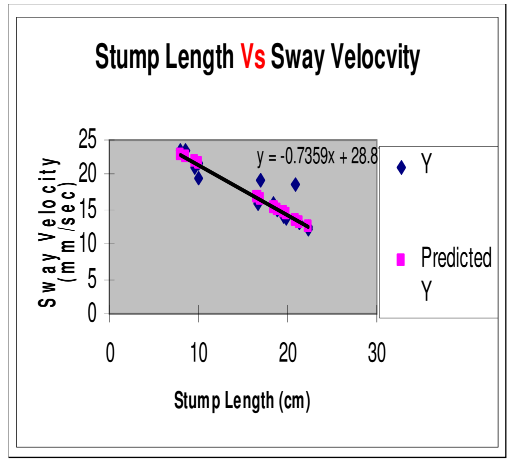

Figure3: Variation of sway velocity with stump length

Discussion

In the present study we measured postural steadiness in two groups of disabled subjects with transtibial amputation. In short stump amputee both sway area and sway velocity was found more than medium stump amputee. The sway velocity increased inversely with the increase in length of the stump as shown in figure-3 in the one dimensional approximation. It may be concluded that higher physiological loss in short stump could be the reason. The sway velocity in short stump was 40% higher than counter part and it may be summarized that postural steadiness is better in medium stump amputee , similar explanation was discussed by Prieto et al (1996) [7]. In order to maintain a stable position it is very important to keep the sway of the body in the cone of stability. The results of sway area indicated 86 % higher in short stump amputee and the similar findings for better stability was discussed by Brouwer et al. and Timothy et al. [37-38]. These results indicated that most standing balance control was carried out by the sound limb and the main direction of sway activity produced to maintain balance was in the AP plane (1.48 times more), similar findings confirm also other [7, 39-40] studies using standing test on healthy subjects which have reported the distribution of sway to be mainly in the AP direction. In fact, it is known that the rigid foot and ankle of the prosthesis impose a higher mechanical stiffness in the AP direction than in the ML direction. Therefore, the balance maintaining reactions in the sound limb were greater in the AP direction in both groups. Short stump amputees postural steadiness in AP direction ($p=0.00055$) was found significantly difference to medium stump groups, indicated more unstable in sagital plane which is comparable to the study of Buckley et al [39]. The Frequency domain analysis showed that the variation of frequency of COP in short stump compared to medium stump group was negligible in medio-lateral (ML) direction. But in anteroposterior direction these variations were much more significant which clinically indicated that postural stability is much more dependent on antero-posterior (AP) direction than in than medio-lateral (ML) direction.

Conclusions

The nature of control mechanism responsible for ensuring stability during quite standing in prostheses-rehabilitee system has been assessed successfully by COP measures. Since larger sway is supposed to relate to instability, the stump length should be considered as design factor while prescribing of prosthetic components.Standing is an unstable position which requires the constant use of muscular activity and joint mobility especially at the ankle, so more loss of residual anatomy more unstable in case of trans tibial amputees. The difference of stability of both groups could be explained in loss of propioceptive and mechanical advantage in short stump. In conclusion, The AP forces involved in balance control are significantly larger in the sound limbs as compared with the affected limbs. Control of the standing balance reactions are therefore performed mainly by the sound limbs of both group of amputees. Rehabilitation programs for amputees should include exercises for improving involvement of the affected limbs in the process of balance maintenance in standing. A better standing balance and symmetrical limb load will result also in improving other motor functions and activities of daily living as well as in ambulation.

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