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Gait Measures and Dynamic Weight bearing in Young and Elder Trans-tibal Amputee using PTB Prosthesis with SACH foot

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Abstract: *Objective:* to investigate the changes associated with age in gait characteristics and dynamic weight bearing pattern of sound and prosthetic limb of persons with unilateral amputation. *Participant:* two groups of seven young (24±3.8 years) and seven elderly unilateral amputee (71±6 years) were selected for this study. *Setting*: both groups walked at their self selected speed over a 20 second duration plane surface walk way in trans-tibial prosthesis with PTB socket and SACH foot. The raw data of force and EMG sensors of gait analyzer were filtered, processed and analyzed with help of 'matlab 7.0. A blue tooth enabled heart rate telemetry system was used for calculating gait efficiency in terms of physiological cost index (PCI). *Results*: significant differences were found in stride duration, ($p=0.003$), step duration sound limb ($p<0.002$), stance duration sound limb ($p=0.002$), stance duration prosthetic limb ($p=0.006$) and cadence ($p=0.001<0.05$), however no difference was found in EMG pattern of vastus lateralis between the two groups. The dynamic weight distribution showed more normalized load on anterior parts of heel and minimum load at calcaneal max in elderly group. The results of vertical ground reaction force found the prosthetic side of elderly group takes more weight than young group during loading response. In comparison, PCI was observed to be greater in case of elderly group. *Conclusion*: most of difference between two groups could be explained by speed variations and biomechanical limitation of ankle joint due to natural aging process.

Keywords: gait analysis, PTB Socket, SACH foot, trans-tibial amputee, dynamic weight bearing

Introduction

The proportion of young to elderly persons in the modern society is changing due to advanced health care system and technological developments. This leads to an increasing population of elderly amputee groups. Especially non-traumatic losses of limbs are most prevalent in aged [1]. It is also imperative that a number of age related disease or condition would be present among the older persons of the society. The other age related factors that may limit walking ability are balance deficiencies [2-4], malnutrition [5-6], medication, risk of falling [7–11] and depression [12]. Presence of such conditions would dictate the nature of the prosthetic design to be adopted in older persons. However, in a developing country detail prosthetic design process is not normally taken up separately for the young and elderly amputees due to various socio-economic constraints. In practice the prosthesis fabrication in

developing countries depend on the availability of the component irrespective of age of the amputee. This kind of practice sometimes leads to inappropriate prosthesis for the older person and complications like damage to the stump, imbalance in bilateral limb-load.
Human locomotion is a dynamic process of transferring body weight from one place to another without loss of equilibrium and prosthesis is an integral part to share load bearing for locomotion. Power et al. study on gait indicated that sound limb takes more load than amputated limb in unilateral trans tibial amputees [13] Two reports have demonstrated that unilateral trans tibial amputees are prone to osteoarthritis in the sound limb with prosthetic use of at least 5 years [14-15]. Long-term prosthetic use and age of the amputee may be a cause to early degenerative joint changes, but a greater implication for elderly amputee with vascular disease is whether increased sound limb loading can be a precursor to early amputation. This suggests that a comparative study of dynamic weight bearing pattern of both young and Elderly is required .Authors in previous study explained the static weight bearing pattern in trans tibial amputee in young active group using SACH foot [16].
Variability in quantitative gait data arises from many potential sources, including natural temporal dynamics of neuromotor control, pathologies of the neurological or musculoskeletal systems, the effects of aging, as well as variations in the external environment, Prosthesis fitment, Gait analyzer and data collection methodologies. A number of studies have been reported regarding the changes in gait with advancing age in healthy individual [17]. Generally the analysis of temporal and distance variables of gait and interactive measures of Centre of Mass (COM) and Centre of Pressure (COP) were compared in the young and Elderly healthy individuals. Larish et al. (1988) showed that the self selected velocity for the old and young is statistically equal (119cm/s and 121cm/s respectively) [18]. Cunningham et al. (1982) showed that similar results and differences resulted only when subjects were asked to walk as fast as they possibly could [19]. Murray et al. (1969) revealed that more than 20% of the subjects in old group walk faster than the average self selected and fast velocities for the young group (less than 60yrs) [20]. When normalize or equated for walking velocity, the older in comparison with the younger group seems to walk faster by relying more on increased cadence or step frequency and less on increased stride length. Similarly most of the current gait research has been performed on young and elderly amputee separately with a control group of normal healthy individual in respective age group. Most of the studies performed are on young amputees and shows an asymmetric gait and slow walk than non-amputee [21-27]. There are very limited studies on elderly amputees [28]. Similar study concluded that amputee gait patterns were more asymmetrical than non-amputees; as the joint angles of the sound leg were different from the joint angles of the prosthetic leg [29]. However a gait study in both young and elderly amputees with similar kind of prosthesis is required to verify the age related gait measures. To prevent difficulties arising from prosthesis-amputee mismatch in older subjects it would be wise to enumerate the differences in gait characteristics between young and older amputees wearing similar types of prosthesis (in design). Present study would focus in this direction to extract gait variation considering age factor with persons with unilateral trans-tibial amputation.

Materials and Methods:

Seven young (24±3.8 years) and seven (71±6 years) Trans Tibial amputees of both sexes were included based on screening to eliminate any orthopedic and neurological disorder. The details of subject information are given in table -1. All the subjects both young and elderly amputees attended our OPD (out patient department) for replacement/recheck up/ repair of their presently used prosthesis. Based on our study requirement the subjects were further explained about procedure of gait analysis, interviewed by clinical psychologist and selection made to those who were willing to sign the consent form. On an average all the subjects were using their prosthesis for a minimum period of two years in case of young and 3 years in Elderly amputee. All of them are using PTB socket with SACH foot. Before Gait analysis every patients were admitted and assessed to ensure optimal fit and function of the prosthesis and ensured that none of the subject had any stump problems like pain, swelling, pressure sores etc. Anthropometric measurements were taken as defined by Dempster (1955). The gait analysis system called CDG (Computer Dynography) supplied by Infrotronics Medical Industrial Engineering [30-33] was used for data collection. Each subject was made to wrap the micro-controller called ultraflex unit around the waist and a pair of foot sensors or CDG shoes of approximate size were put below the normal and prosthetic foot to collect normalized force distribution. During the gait analysis session foot sensors, EMG, Gonio etc were placed as per guideline of the CDG manufacturer. At first the subjects were under went a trial walking and after getting acquainted with the system they were asked to walk in self selected speed for 20seconds durations on a plane surface with CDG system fitted with sensors.

Table -1. Subject and prosthetic parameter in Young subjects and Elderly subjects

	Young(Mean ± standard deviations)	Elderly(Mean ± standard deviations)
Age (years)	24±3.8	71±6
Height(cm)	169.22±3.03	164.35±5.08
Weight(kg)	55.48±9.61	59.66±6.88
BMI(kg/sq.m)	19.35±3.09	22.17±3.02
Socket	PTB	PTB
Foot	SACH	SACH

Results

Stride Characteristics: A total of 15 stride parameter were calculated (velocity, cadence, stride length, gait cycle duration, double support, single support, stance duration, step duration prosthesis, step duration normal, swing duration prosthesis, swing duration normal, symmetry stance, symmetry step duration, symmetry double support, symmetry swing), out of which significant differences were found in stride duration, (p=0.003) , step duration sound limb (P<0.002), stance duration sound limb (p=0.002), stance duration prosthetic limb(p=0.006) and cadence (p=0.001<0.05) in single factor ANOVA between two age group. There was no statistical difference found between swing characteristics of both prosthesis and sound limb. The symmetry of double support (Prosthetic side/ step length Sound limb) is better in young than Elderly and also a significant statistical difference was found between two group (p=0.02 < 0.05). The step length symmetry of young were observed to be better than elderly and walking velocity of young were found to be more than elderly, the similar findings in walking velocity was explained by McGibbon et al. [34]. The important stride parameters are shown in table -2.

Table-2: Stride parameters of both young and elderly amputees

Subjects	Velocity (Km/hr)	Cadence (Steps/ Minute)	Stride Length (Meter)	Ste (amputated side)	Step Length (Sound side)	Step Length Symmetry (Amputated/Sound)
Young	4.038±0.520	101±11.85	1.36±0.17	0.676±0.09	0.685±0.08	99%
Elderly	2.402±0.489	81±9.3	0.99±0.22	0.492±0.13	0.509±0.133	93%

Normalized Vertical Ground Reaction Force:

The Vertical forces from the sensors were normalized to subject's body weight. The 20 second force data received form Gait Analyzer of each subject (Both young and Elderly) was averaged to one gait cycle. A significant difference was found at heel strike (0 to 20% of gait cycle), p=0.0361 between two group. The result showed that elderly group took more load in prosthesis limb than young group at loading response in self selected velocity. The duration of both 1st peak and 2nd of vertical ground reaction force were found more in Elderly group. The average responses of vertical ground reaction force of both young and elderly groups are shown in figure-1. The 'x' axis represents the deviations of load (Prosthetic limb- Normal Limb) and 'y' axis represents the vertical ground reaction force in terms of percentage of the body weight. The difference of result may be due to slow walking, joint power and other age related factor. Results also indicated that during push off phase of gait cycle, the sound limb of Elderly group took more weight than young (a difference of 10% of body weight between two groups).

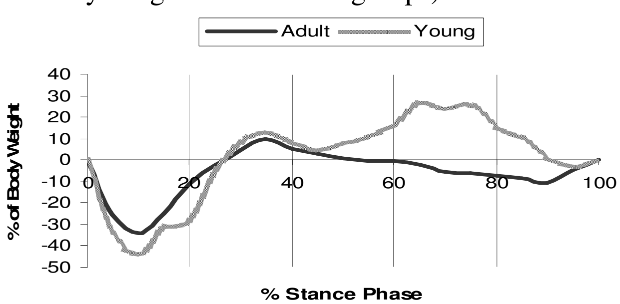

Figure-1: Average Loading of Prosthetic limb in both young and Elderly in reference to sound limb

Dynamic Weight bearing distribution:

The total weight bearing areas of each foot was divided into 8 parts as shown in figure -2 as per the inbuilt sensors placement in CDG shoes. The data were recorded during walking in both prosthetic and normal foot. The mean load at each sensor was calculated from both stance and swing phase of all gait cycles in each foot (Load at sensors is zero in swing phase) and total dynamic vertical forces were shared by both prosthetic and normal foot. The mean and standard deviations of percentage of load of 8 sensors with respect to total load on each sound and prosthetic limbs are given in table -3. A significant difference was found in load distribution at posterior heel (Sensor 1) of prosthetic leg in young and Elderly group (P=0.017), however total load on heel (Sensor 1+ Sensor2 +sensor3) in both the cases are nearly equal (40%). In comparison, the load at posterior heel of prosthetic side was found more in young group and load at anterior medial (Sensor 3) and anterior lateral (Sensor 2) of heel were found more in case of elderly group. The mid sole in prosthetic foot took more load than toe break region in both young and elderly as shown in figure-3, but in sound leg load at toe break and mid soles were nearly equal as shown in figure-4. The comparison of lateral and medial load distribution shows, load at medial sole (3+5+7) is higher than lateral for Elderly and the same is opposite in young.

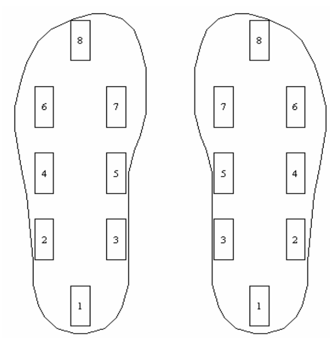

Figure-2 : Sensor placement in CDG shoes;1-posterior heel, 2- lateral heel , 3- medial heel, 4-lateral mid sole, 5- medial mid sole, 6- lateral toe break, 7- medial break, 8-tip of finger

Table-3: Dynamic load distributions of 8 sensors in CDG shoe

Sensors	1	2	3	4	5	6	7	8
Young (N)	22.07±7.9	10.86±3.2	9.15±2.7	17.69±3.9	11.52±4.5	9.45±4.6	13.93±3	5.33±2.7
(P)	18.10±5.6	13.68±5.2	8.82±4.7	22.90±7.5	17.57±6.7	8.70±4.1	6.44±1.7	3.79±0.9
Elderly (N)	5.09±1.6	14.83±6.4	16.38±5.4	11.44±6.9	15.82±9.8	13.99±4.8	14.73±4.2	7.71±5.6
(P)	8.52±7.4	15.48±10.7	16.06±10.2	13.75±8.4	19.84±15.8	10.94±8.6	11.53±5.6	3.88±2.4

N: Normal, P: Prosthetic

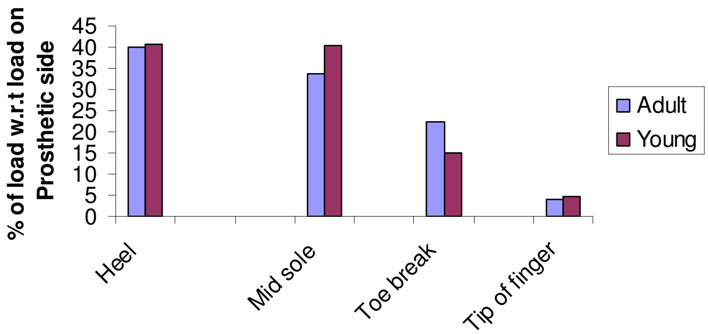

Figure-3: Dynamic load distributions on prosthetic side

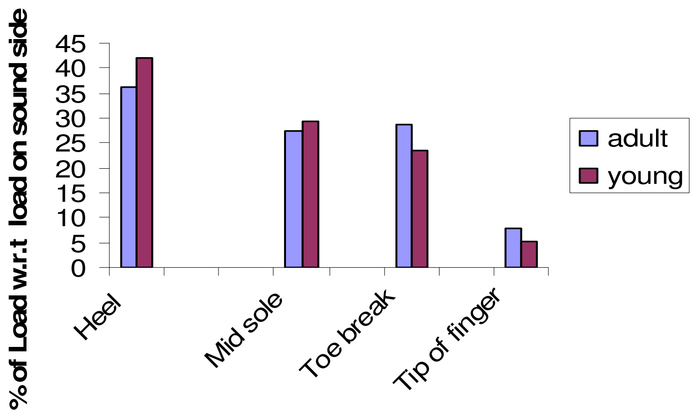

Figure -4 Dynamic load distributions on sound side

EMG Analysis: The largest and strongest component of quadriceps is the Vastus Lateralis and both Vastus Lateralis and Medialis acts equally through the range of motion in normal human locomotion [35]. In this study to verify impact of different foot in quadriceps muscle activity, the EMG data of Vastus Lateralis was taken. 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%) [36] Each stride was divided into 10% interval and average peak amplitude of ten strides for each subject was given a value 100%. Similar normalization was adopted by knutsson and Richards [37]. 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) for seven subjects was calculated for each 10% of gait cycle. There was no statistical difference of percentage of Maximum Gait Contraction in sound side comparison of both group however mean peak contraction in Elderly stayed more time (30% of swing phase) than young (10% swing phase) as shown in figure-4. In prosthetic side the intensity duration of young was more than elderly.

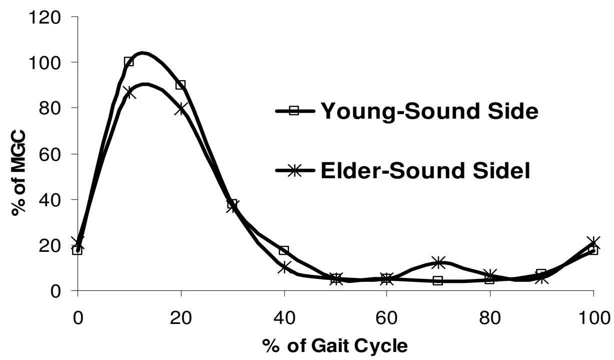

Figure-5: Electromyography pattern of Vastus Lateralis in Sound side of both Groups

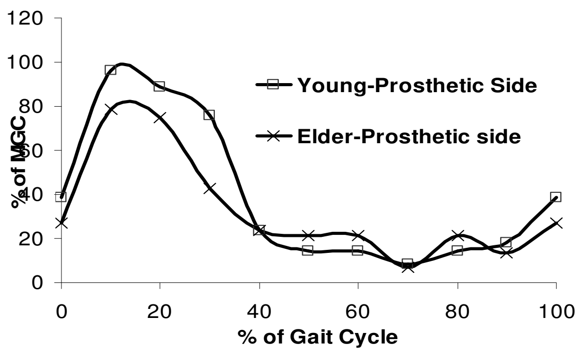

Figure-6: Electromyography pattern of Vastus Lateralis in Prosthetic side of both Groups

*PCI data***:** Physiological Cost Index (PCI) of walking as developed by Butler et. al. [38] was used in this study to determine difference of index of energy consumption in both young and Elderly group at self selected velocity. The PCI was calculated by dividing the velocity in Km/hr to the difference of heart rate (Heart Rate after a fixed time of 20sec walking in plane surface and at Rest). The results indicated higher PCI in Elderly group.

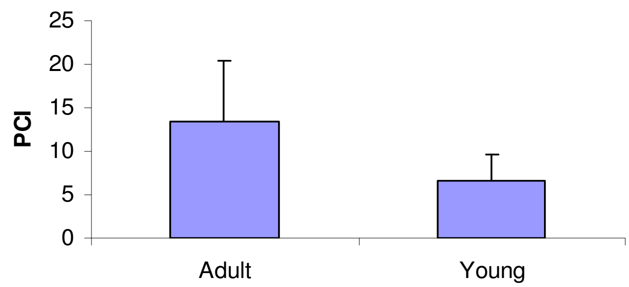

Figure-7: The Mean and Standard Deviations of Physiological cost index in both group

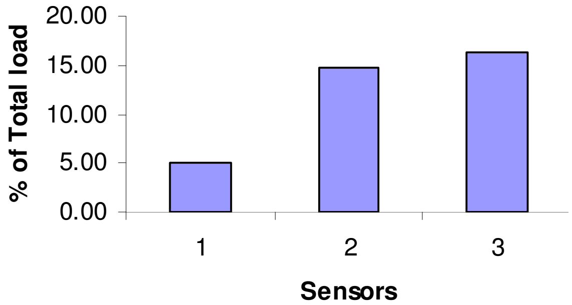

Figure 8: Dynamic load distribution of Sound side in Elderly

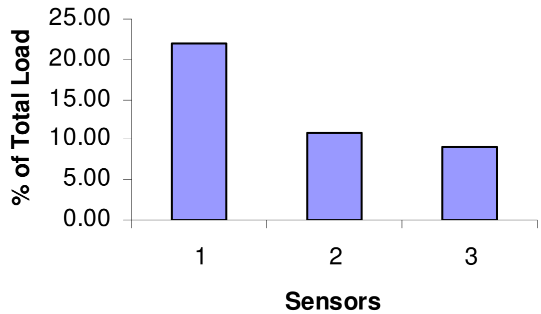

Figure 9: Dynamic load distribution of Sound limb in Young

Discussion

The result of stride characteristics suggested that elder amputee walk slower than young amputee (P<0.0001). Beyond normal age, it has been seen that elderly walk more slowly than younger group due to natural aging of locomotor systems. As reported by Murray et al. 1967, most Elderly able-bodied ambulators walks at a rate of 1.2 to 1.5 meter/sec in self selected speed [39], however the result of this study on amputee showed decrease in speed in comparison to able persons. One of the major factors associated with this functional limitation is ankle plantar flexor power in late stance phase or push up of gait cycle. The study made by Mc Gibbon et.al. (1999) reveled that ankle plantar flexion power were significantly higher for healthy elderly in compared to functionally limited elders (p<0.0003) but were not significantly different between young and healthy subjects [34]. The results of study in velocity difference supported this observation on ankle limitation of sound leg in elderly. The results showed that stride length of young amputee was 36% greater than elderly and a statistical significant difference was found (P<0.006) and similar findings were indicated by Elbel et al. 1991.Murray et al. 1969 and Winter et al. [39-41]. The results of our study indicated the gait variability in young and elder amputee was more than variability between healthy young and elder. Similar findings were reported by Selikatar and Mizrahi et al. [42]. No major difference was found in step length (Prosthesis/Sound leg) symmetry but major difference found in double support duration symmetry between two groups. The results of the vertical ground reaction force study indicated that the sound limb of both groups took more weight during initial loading; this is in agreement with studies by Power et al. [13] and Snyder et al. [43]. The comparative results of our study in both group showed that sound limb loading in young groups were more than elderly during initial loading, the reason may be walking velocity. The walking velocity and vertical ground reaction force has been found linear in relation during loading response by a study on loading of lower limb [44]. The result from figure 1 indicated during push off phase the sound limb loading is less in comparison to prosthetic limb of young group and the same is reverse in Elderly group, the changes could be due to speed of walking and inability to plantarflex in SACH foot. The young group exerts more force in prosthetic limb in push off phase in order to accelerate the body for forward progression or to quick transfer body weight from prosthetic limb onto sound side for walking with more speed. One of the major factors for explanation of kinematics difference between two groups may be due to functional limitation of ankle mechanism due to aging process, similar study in transtibial amputee and normal, discussed the importance of ankle mechanism and the compensatory actions required to overcome the limitation by prosthetic user[21].There was no significant variation of mean dynamic weight bearing distribution in gait cycle of both group in prosthetic side and sound side in terms of heel, mid sole and toe break in combination; however the individual sensor loading especially at heel regions were totally different as shown in figure 8 and 9. The Increase order of load from posterior heel to anterior heel in elderly may be due to improper heel strike or flexed knee gait. As reported by Begg et al (2005), elderly preferred flexed knee gait and the results also reflected the same [45]. The proper gait training, stump exercise and alignment of prosthesis may be the remedial measure to improve gait pattern. The posterior heel or calcaneal max was indicating minimum load in elderly group, similar findings were discussed in a comparative study of foot pressure distribution in normal young and elderly group [46].The results of EMG study did not show any significant difference between two groups. The normalized amplitude curves as shown in figure 5 and 6 for both groups were similar in shape but peak value during swing were higher in both prosthetic side and sound limb for young group. The large eccentric contractions of flexor group may occur in response to fast leg movement of young group in comparison. The results of physiological cost index were higher in Elderly group in our study which may be due to slow walking speed.

Conclusion

Among the Gait parameter velocity, symmetry and dynamic weight distributions were found to be different in both groups. Gait variability between young and elderly amputee was found to be higher than healthy young and elder group. One of the important findings was the prosthetic side of elderly group takes more weight than young group during loading response. The Medial sole of the prosthetic foot was found more prone to vertical loading than lateral sole in adult group and same was opposite in young group These phenomena may be considered by Prosthetist while designing prosthesis for elderly. Most of the difference between two groups could be explained by speed variation and biomechanical limitation of ankle joint due to natural aging process.

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