Gait Pattern with the Use of Two different Prosthesis on Amputated Limbs in Trans-Tibial Amputees

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ABSTRACT

This study was to analyze the gait pattern of the amputated limb using two different types of prosthesis commercially available for the trans-tibial amputees. The study was conducted on 5 adult males with right trans-tibial amputation. Stride characteristics, joint motion and ground reaction forces were recorded simultaneously during a self-selected free walking velocity by using two different prosthetic feet by the trans-tibial amputees, namely DR (Dynamic-response) and SACH (Solid Ankle Cushioned Heel) foot. Qualisys Motion Capture System (Sweden) and Kistler Force Plate (Switzerland) were used to capture and analysis of data. The volunteers had trials on each foot considerably prior to experiment. Mean ±SD of the age, height and weight of the volunteers were 40.2±5.93 yrs, 172.6±11.23 cm and 71.0±12.04 kg respectively. It was observed that walking speed using DR foot and SACH foot were 0.99±0.17 m/sec (3.56 km/hr) and 0.87±0.23 m/sec (3.13 km/hr) respectively. Step lengths using DR foot (L =0.7±0.11m; R=0.6±0.05m) are more than the step length using SACH foot (L=0.6±0.09m; R=0.4±0.25m). Vertical ground reaction force for amputated leg using DR foot (28.9±19.63 N) was more than SACH foot (14.13±17.54 N). The volunteers were asked to walk on the treadmill in two different Phases using DR and SACH feet. Steady state heart rate was recorded using polar HR Monitor – S810i (Finland). In Phase-1 they were allowed to walk at their normal walking speed for 5 min and in Phase-2, treadmill elevation was 4% along with their normal walking speed. The heart rate responses in Phase -1 for DR and SACH foot were 115.2±13.68 and 121.7±18.63 respectively. Whereas, the heart rate responses in Phase-2 were 117.4±11.11 and 125.7±19.18 respectively. The findings of this study shows that gait pattern of the amputated limb with DR prosthesis has greater floor impact in comparison to SACH foot and is closer to the 'sound' limb. Also physiological responses are comparatively better for DR prosthesis than SACH. Therefore, the DR prosthesis has been found functionally better suited for trans-tibial amputees than SACH prosthesis.

Key words: trans-tibial amputee, walking speed, ground reaction force, prosthetic foot, steady state

INTRODUCTION

Human Locomotion is the process to move about on two legs in an upright position. The main three functions of lower limbs of human areto bear weight, provide means for locomotion and maintain equilibrium. But it is mainly adapted for stability that depends on the major joints, strong ligaments of the lower limb. The rhythmic alternating movements of the two lower limbs helps in the forward movement of the body and the manner in which it occurs i.e. how a person walks is what is known as gait.

There are three main phases of gait i) Stance phase (support) - begins when the heel of the forward limb makes contact with the ground and ends when the toe of the same limb leaves the ground. ii) Swing phase (no support) - begins when the foot is no longer in contact with the ground. The limb is free to move. iii) Double support - both limbs are in contact with the ground simultaneously. The activity that occurs between heel strike of one limb (reference limb) and the subsequent heel strike of that same limb is known as gait cycle.
Loss of normal gait pattern in a person is caused due to lower limb amputation. Amputation is one of the most emotionally upsetting and traumatic events that a patient can undergo [1]. The lower extremity amputees have to spend huge effort &time to achieve their goals. Achieving the efficientlocomotion plays a major role in the individual development [2]. Most of those amputees achieved their normal gait within their limitation ofdisabilities. Prosthetic foot is an artificial device that is normally used to replace such alimb, i.e. replacement of a missing limb or part of a limbwith such a device.The physical parameters & quality of life are thefactorslike physical parameters and quality of life are actually affecting the performance of the volunteers. Selection of a prosthetic foot in developing countries depends on many factors like amputees' physical and psychological attributes, financial resources, availability and maintenance of feet. Gait analysis has been considered as a useful tool for evaluating an amputee's prosthesis by providing objective measurements that characterize thewalking pattern [3].
Many technological developments have been seen in the field of lower limb prosthetics since the last decade with a greater understanding of biomechanics, extensive use of different techniques and the availability of specific materials. Amputees have also greater desire to participate in recreational and sporting activities, so their expectations increases and these have led to the evolution of several new designs of prosthetic foot [4].Basic requirement of lower limb prosthesis is to restore appearance and lost functions in individuals with amputation [5].Load bearing, leverage, shock absorption, stability and protection are the functions offeet in lower limb prosthetic management [6,7]. Two types of prosthetic feet are widely used by the trans-tibial amputees namely Dynamic Response (DR) and Solid Ankle Cushion Heel (SACH). The efficiency of the prosthetic feet depends on the range of motion, storage & return of energy and low impact to sound leg during loading. Therefore, the present study was taken up forbiomechanical analysis of the gait pattern of DR and SACH prosthesis in trans-tibial amputees.

The objective of this study was -

1. To study was to analyze the gait pattern of the amputated limb using two different types of prosthesis commercially available for the trans-tibial amputees.
2. To determine the effects of prosthetic foot design on the vertical ground reaction forces experienced by the 'sound' and 'amputated' limbs in case of trans-tibial amputations.
3. To compare the heart rate responses after using both the prosthesis while walking on the treadmill at a sub-maximal speed.

4. To suggest the suitable prosthesis for the trans-tibial amputees.

MATERIALS AND METHODS

The study was conducted on 5 adult males with trans-tibial amputation in the age range of 37 to 49 years. All the volunteers were from Mumbai who had lost their right leg (below knee) in accidents.The volunteers were explained about the experiment had trials with each prosthetic foot considerably prior to experiment.A written consent was obtained from all the subjects prior to the study.

Equipment used

Following equipments were used for collection of data:

- Qualisys Motion Capture System (Sweden)
- Kistler Force Plate (Switzerland)
- Footscan System (Belgium)
- Polar Heart Rate Monitor-S810i (Finland)

Methodology

Sequence steps for methodology are as under:

1. Force plates were calibrated
2. Thirty six reflective markers were placed on each volunteer's legs and pelvis in total.The volunteer's lower body, beginning with the pelvis, was equipped with markers. The defining landmarks for the markers, which enabled Visual 3D to reconstruct the digital skeleton of the volunteer, included the following: Anterior Superior Iliac Spine (ASIS), Posterior Superior Iliac Spine (PSIS), Hip, Thigh, Knee, Sank, Heel, Toe, ankle, and metatarsal.
3. Volunteers were asked to walk on the force plates with a self-selected free walking speed using two different prosthetic feet namely SACH and DR prosthesis. Volunteers used each foot considerably prior to testing.
4. An array of six high speed cameras (QualisysProReflex MCU) by Qualisys Motion Capture System (Sweden) was used to film the volunteer walking along a 5 meter walkway.Two Kistlerforce plates were used independently to determine the resulting moments and power in the volunteer's hip, knee and ankle joints for the right leg. Each volunteer walked along the 5 meter walkway at his self-selected speed without any load.The volunteers were allowed to walk on both the force plate-1 and force plate-2 by left foot and right foot respectively. The movement by using DR and SACH prosthesis on right leg was captured by the QualisysProReflex MCU. The best of the trials were considered for analysis.
5. Markers were identified by using Qualisys Track Manager (QTM) software and gait standing trial was formed.
6. To reconstruct the volunteer's lower body's anatomy digitally, 'Visual 3D' software was used. Standing model was merged into walking model and analyzed (Fig 1 & 2).

7. Volunteers were asked to stand on the foot scan and static scan was captured using Balance software.
8. Volunteers were asked to walk on the foot scan and dynamic scan was captured.
9. The volunteers were asked to walk on the treadmill in two different Phases using SACH and DR feet. Steady state heart rate was recorded using polar HR Monitor – S810i (Finland).In Phase-l: Normal walking speed for 5 min at 3.56kmh (DR) and 3.13kmh (SACH) respectively. In Phase-ll: 4% elevation was given with normal walking speed.

Data processing

From the successful trials recorded for each condition, the three best were selected for analysis by visual inspection, omitting data which appeared abnormal. Mean and SD was calculated and t test was applied to observe the significance level unlessotherwise stated. Following parameters were studied:

a) Biomechanics
- Gait pattern -Walking speed, Step length, Cadence, Stance time
- Foot biomechanics - Heel strike force, Toe off force, Active contact area

b) Physiology
- Steady state heart rate

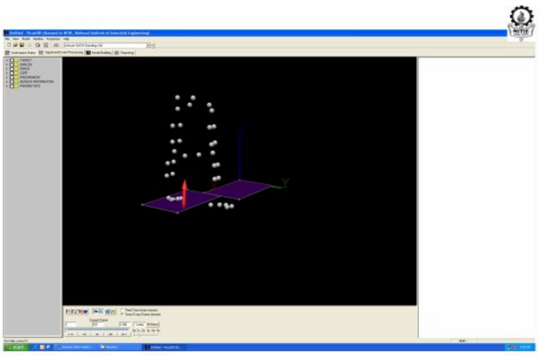

Fig 1: Reflection markers

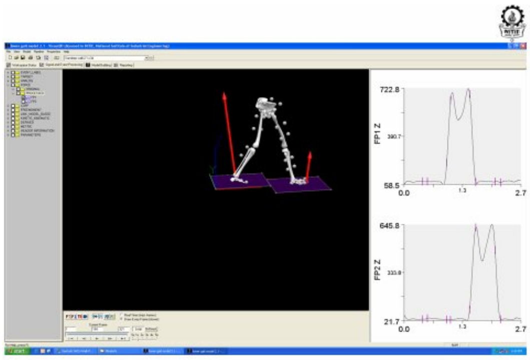

Fig 2: Construction of walking model

RESULTS AND DISCUSSION

Mean ±SD of the age, height and weight of the volunteers were 40.2±5.93 yrs, 172.6±11.23 cm and 71.0±12.04 kg respectively (Table 1).

Table 1: Physical profile of the volunteers

Variables	Age (yr)	Height (cm)	Weight (kg)
Mean	40.2	172.6	71.0
±SD	5.93	11.23	12.04

Effectiveness of the prosthetic foot depends on increased gait parameters like walking speed and step length. Walking speed using DR foot and SACH foot were 0.99±0.17 m/sec (3.56 km/hr) and 0.87±0.23 m/sec (3.13 km/hr) respectively. Step lengths using DR foot (L =0.7±0.11m; R=0.6±0.05m) are more than the step length using SACH foot (L=0.6±0.09m; R=0.4±0.25m). Similar type of findings observed by Sutherland *et al.* 1988 [8], which shows significantly increased prosthetic step length and walking speed during walking.Cadence rate for DR and SACH foot was recorded as 96.28 steps/min and 93.58 steps/min respectively.This finding is in agreement with Lenka and Kumar 2010 [5] in which six different prosthetic feet was studied by using Computer Dynography (CDG) and EMG analysis which states that velocity and cadence is higher in Dynamic foot than the SACH foot. Though there is no statisticaldifference between step lengths using the DR and SACH feet but the DR foot produces increased step length and cadence.Stance time is slightly higher in SACH foot than DR Foot.

Table 2: Gait parameters during walking

Variables	DR Foot Mean ±SD	SACH foot Mean ±SD
Walking speed (m/sec)	0.99 ±0.17 (3.56 km/hr)	0.87 ±0.23 (3.13 km/hr)
	P < 0.07	
Step length (m)	L = 0.7 ±0.11 R=0.6 ±0.05	L= 0.6 ±0.09 R= 0.4 ±0.25
Cadence (Steps/min)	96.28 ±10.92	93.58 ±17.12
Stance time (Sec)	L= 0.810.10 R= 0.840.17	L = 0.83 ±0.22 R = 0.85 ±0.22

The impact force peak is sharp and is associated with heel strike. Studies show that amputees land more softly on the prosthetic foot probably because they feel less secure with an artificial limb as compared to the normal leg and therefore, load it cautiously [4]. In the present study Heel strike force in case both the DR and SACH feet have found lower than the normal leg (left leg) and they are significant at $p<0.04$ and $p<0.05$ respectively with normal leg. Lower impact load rate would imply that more ground reaction forces are being absorbed at foot level, hence the better shock absorption capacity of the prosthesis. In this study, the DR foot produced the smaller forces, apparently indicating its better shock absorption capacity compared to the SACH foot.

The Toe off (propulsive) force peak represents the push-off force of the foot as it drives off into the next stride [9]. The greater push-off capacity of the energy storing prosthetic feet has often been claimed because of a larger propulsive force peak [10]. Though the active contact area has been found similar in both the prosthesis but Toe off force for amputated leg using DR foot (28.9±19.63 N) was more than SACH foot (14.13±17.54 N).

Table 3: Kinematic responses during walking

Variables	**DR Foot** **Mean ±SD**	**SACH foot** **Mean ±SD**
Heel strike force (N)	L = 66.30±45.77 R=58.08 ±40.30 P<0.04	L= 63.58 ±92.65 R= 80.98±101.58 P<0.05
Toe off force (N)	L = 54.38±44.55 R= 28.9 ±19.63	L = 30.48±27.89 R = 14.13 ±17.54
Active contact area(cm^2)	L = 10.9 ±5.71 R = 9.0±5.51	L = 10.5 ±5.91 R = 10.3 ±3.98

Physiological responses of DR and SACH foot were studied by analysing the heart rate responses after a treadmill walking. In Phase-1 they were allowed to walk at their normal walking speed for 5 min and in Phase-2, treadmill elevation was 4% along with their normal walking speed. The heart rate responses in Phase-1 for DR and SACH foot were 115.2±13.68 and 121.7±18.63 respectively. Whereas, the heart rate responses in Phase-2 were 117.4±11.11 and 125.7±19.18 respectively (Table 4; Fig 3). Though there was no statistical significance was observed between the heart rate responses of DR and SACH feet, but DR foot has lower heart rate responses than the SACH foot during walking therefore exhibiting lower cardiac load to the amputee.

Table 4: Steady state HR responses using DR and SACH foot

Variables	DR foot (b/min) Mean ±SD		SACH foot (b/min) Mean ±SD	
Phase l	115.2	13.68	121.7	18.63
Phase ll	117.4	11.11	125.7	19.18

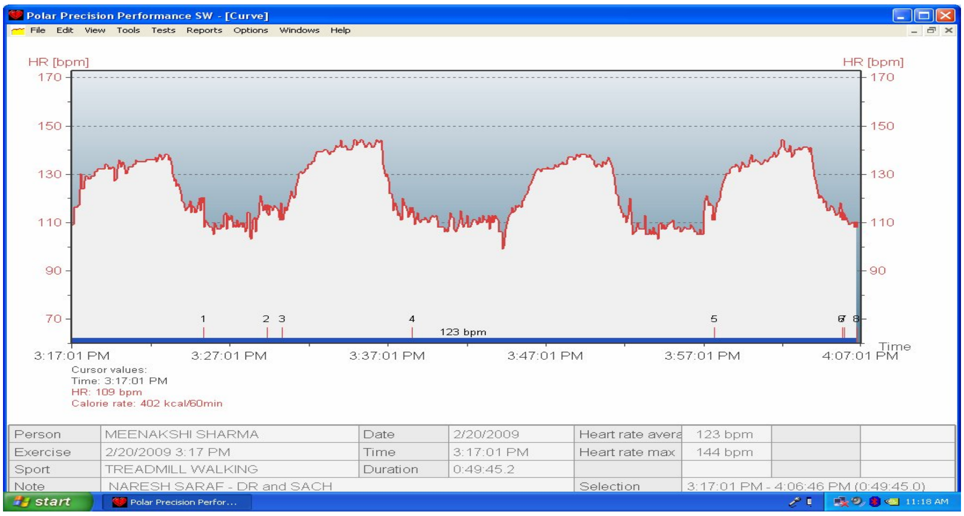

Fig 3: Steady state HR responses using DR and SACH foot

The findings of this study shows that gait pattern of the amputated limb with DR prosthesis has greater floor impact in comparison to SACH foot and is closer to the 'sound' limb. Also physiological responses are comparatively better for DR prosthesis than SACH.

CONCLUSIONS

There is often a tendency amongst the users to fit a more expensive device, whether or not the amputee can use it effectively. This is due to many factors, one being the amputee who 'wants the best' and believes the best must obviously be the most expensive. The functionality of the prosthesis needs to be ensured before using the same. It can be concluded from the study that:

1. Gait pattern (walking speed, step length, cadence, stance time) of DR prosthesis is functionally closer to the sound limb than the SACH foot.
2. The DR foot has a better shock absorption capacity than the SACH foot which evident from lower heel strike force in DR foot.
3. DR foot produces higher Push off force than SACH foot.

4. Heart rate responses during walking on the level ground as well as slope walking is lower in case of DR foot than SACH foot, which indicates lower cardiovascular load for DR foot.

Selection of a prosthetic foot in developing countries depends on many factors like amputees' physical and psychological attributes, financial resources, availability and maintenance of feet. Gait analysis has been considered as a useful tool for evaluating an amputee's prosthesis by providing objective measurements that characterize the walking pattern. Therefore, the present study will be useful to select the suitable prosthesis for the trans-tibial amputees.

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