IMPROVED SOCKET PERFORMANCE AND FIT FOR TRANSFEMORAL AMPUTEES

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INTRODUCTION

Persons with transtibial and transfemoral amputation experience changes in the fit of their socket over time. These changes arise from changes in the volume of the residual limb that result from weight gain and loss, muscle atrophy, and extra-vascular fluid movement through the lymphatic system. Residual limb volume changes have been well documented with large changes in volume being observed over the course of the day and even shorter periods of time. For example it was demonstrated that residual limb volumes can change by as much as 11.3% after a half-hour of walking[1]. It was also found that limb volume changes over the course of six months were significantly larger than changes the group observed over the course of the day. Substantial changes in limb volume can lead to a poor socket fit, which was reported to be the primary prosthetic-related concern of persons with lower-limb amputation[2]. In addition, poor socket fit has been shown to cause skin breakdown and gait instability.[3]

The adjustable socket has two distinct goals: to accommodate for volume change in the residual limb and increase function during gait. For the proposed study, gait and sway parameters will be measured to allow an evaluation as to whether the new socket design can provide a more efficient and less variable gait patterns.

METHODS

• Data from nine transfemoral amputee subjects were collected for this study. An adjustable socket was custom fabricated for each subject and allowed for a percentage of volume increase (Table 1). All procedures were IRB approved and subjects provided informed consent prior to testing.

Table 1: Subject Demographics

Subject	Prosthetic Leg	Gender	Height (cm)	Weight (kg)	% Oversize Socket
1	L	F	172.7	70.3	3.96
2	R	F	152.4	52.2	9.25
3	R	M	175.3	72.6	2.86
4	R	M	188.0	111.1	6.46
5	L	F	165.1	55.8	7.57
6	R	M	104.1	83.9	11.72
7	L	M	182.9	98.4	6.31
8	L	M	180.3	83.0	5.23
9	R	F	170.2	99.8	14.04

•Three-dimensional kinematic and kinetic data of the trunk, pelvis and lower extremities during walking was collected for each subject in three conditions: 1) their own socket, 2) the fitted adjustable socket, and 3) the loose adjustable socket (Figure 1). Subjects were required to doff their prosthetic between conditions for a period of 20 minutes to allow the residual limb to return to a steady state volume.

•Sway parameters were determined with eyes opened, eyes closed and in a tandem stance.

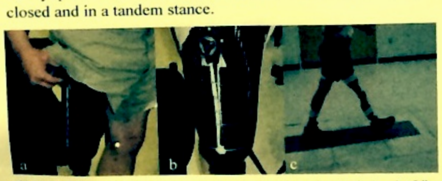

Figure 1: Subject wearing adjustable socket. (a) user tightening socket; (b) check socket fully tightened; (c) walking

RESULTS

• Significant results were found more proximally at the pelvis and trunk (Figure 2 and 3). Increased rotational range of motion (ROM) demonstrated compared to typical walking (the grey band) is noted in almost every subject. This increased ROM tends to occur in all conditions. It is very characteristic of above knee amputee gait patterns. This motion helps with propulsion of the LE, and compensates for the lack of hip, knee and ankle power on the prosthetic side.

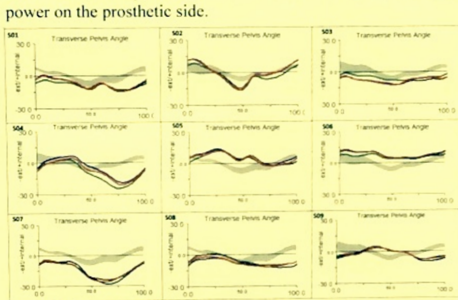
S01 Transverse Pelvis Angle
S02 Transverse Pelvis Angle
S03 Transverse Pelvis Angle
S04 Transverse Pelvis Angle
S05 Transverse Pelvis Angle
S06 Transverse Pelvis Angle
S07 Transverse Pelvis Angle
S08 Transverse Pelvis Angle
S09 Transverse Pelvis Angle

Figure 2: Prosthetic Limb Mean Transverse Pelvis Angle for each subject: green = own socket, blue = loose socket, red = fitted socket. The wide gray band represents the mean transverse pelvis angle for able-bodied individuals ±1 SD. The x-axis represents 100% of the gait cycle of the prosthetic limb from initial contact at 0% to the following initial contact on that limb at 100%.

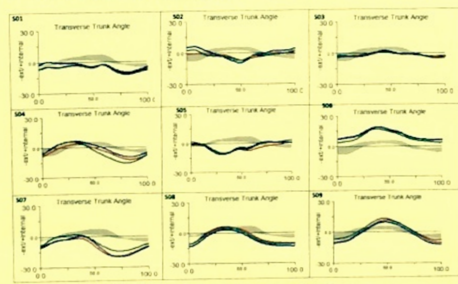
S01 Transverse Trunk Angle
S02 Transverse Trunk Angle
S03 Transverse Trunk Angle
S04 Transverse Trunk Angle
S05 Transverse Trunk Angle
S06 Transverse Trunk Angle
S07 Transverse Trunk Angle
S08 Transverse Trunk Angle
S09 Transverse Trunk Angle

Figure 3: Prosthetic Limb Mean Transverse Trunk Angle for each subject.

• In the hip coronal pane moment, a small but significant difference was found between the Fit and Loose conditions (RMS difference Own-Fit = 0.07 Nm/kg , Own-Loose = 0.06 Nm/kg, $p = 0.053$). This 0.01 difference in variance between the conditions is equivalent to a 10% difference in max coronal hip moment value during stance. The coronal plane hip moment is reduced in most of the subjects in all 3 conditions, indicating reduced hip abductor strength on the prosthetic side. This is often related to residual limb length in above knee amputees.

• The root mean square difference between conditions for a particular gait parameter was determined. This technique was used to summarize complex information contained within the kinematic and kinetic data. This represents a measure of gait differences and can evaluate the quality of motion in relationship to a norm. In this case, the subject's own socket was considered the gold standard. The RMS difference metric gives the average difference between the two joint angle curves (Table 2).

Gait Parameter	RMS OWN-FIT	RMS OWN-LOOSE	P-Value
Sagittal Plane			
Prosthetic Trunk Angle	4.8°	[illegible]	[illegible]
Intact Trunk Angle	4.2°	2.6°	[illegible]
Intact Knee Power	0.25 W/Kg	0.18 W/Kg	[illegible]
Coronal Plane			
Prosthetic Hip Moment	0.07 Nm/Kg	0.06 Nm/Kg	0.053
Intact Hip Moment	0.10 Nm/Kg	0.07 Nm/Kg	[illegible]
Intact Hip Power	0.11 W/Kg	0.08 W/Kg	[illegible]
Transverse Plane			
Prosthetic Trunk Angle	[illegible]	[illegible]	[illegible]
Prosthetic Pelvis Angle	[illegible]	[illegible]	[illegible]
Intact Trunk Angle	[illegible]	[illegible]	[illegible]
Intact Pelvis Angle	[illegible]	[illegible]	[illegible]

Table 2: RMS gait parameters: the subject's own socket was considered the gold standard. Therefore comparisons were made between "Fitted" and "Own" conditions and likewise between "Loose" and "Own" conditions. Root Mean Square (RMS) differences of the mean joint angles, moments and powers were calculated to conduct the comparisons (i.e. RMS Difference = RMS [mean sagittal hip angle Fit – mean sagittal hip angle Own]).

•Sway parameters were used to characterize balance during quiet standing using traditional stabilogram analyses (Figure 4).

•An ANOVA was performed to determine differences across conditions (own, fit, loose) in the four postural sway parameters. No significant differences could be attributed to the socket type. However, there were differences in several variables between

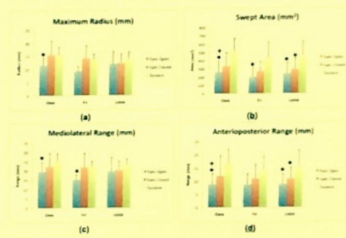

Figure 4: Traditional sway parameters calculated from the position of the COM for all three conditions: (a) the maximum radius of sway, (b) the area swept by the stabilogram, (c) the range of the medial-lateral and (d) anterior-posterior excursions. *Significantly different from tandem stance. +Significantly different from eyes closed. $p < 0.05$

DISCUSSION

Few gait or balance parameters showed a significant difference between socket conditions. Differences were found between several measured kinematic and kinetic parameters and normal gait values. Variances tended to be significantly larger at the trunk pelvis and hip perhaps indicating an inconsistent dependence on the upper body during gait. There are several reasons we these results may have been achieved. First, subjects may not have been given enough time to accommodate to their new sockets. Any discomfort could have caused the subjects to walk in an abnormal pattern. Second, the differences in socket volume may have confounded the results. We attempted to evaluate the effect of percent available increase in socket volume by correlating this value with the calculated RMS values for the gait parameters. The results appear promising but more data is needed to be more conclusive. Lastly, the small number of subjects may not have given us enough power to sufficiently detect small differences in the gait and sway parameters between conditions.

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