

# Analysis of Plantar Pressures and Gait Characteristics in a Post-Surgical Walking Boot With and Without a Contralateral Limb Length Adjustment Device

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## ABSTRACT

This pilot study investigates the effects of a novel shoe sole attachment, the Evenup device, designed to reduce the functional limb length discrepancy (LLD) created by wearing a CAM walker. Ten healthy subjects participated in this study. In-shoe plantar pressures, activities of daily living and temporal and spatial footfall parameters were collected in three different conditions: (A) New Balance walking shoes, (B) New Balance walking shoe plus Evenup and CAM walker, and (C) New Balance walking shoe and CAM walker. Gait speed and plantar pressures were significantly lower in the boot conditions. Most of the differences between the two walker conditions were minor, but the subjects related more comfort and confidence when walking with the Evenup device.

## PURPOSE

To explore if a contralateral shoe sole attachment device improves gait, decreases plantar pressures, and provides the patient with increased comfort and stability.



**Figure 1. Evenup device**  
Contralateral shoe sole thickening device used to correct for LLD caused by wearing a CAM walker. Removable layers allow for easy thickness adjustments.

## LITERATURE REVIEW

The CAM walker has become increasingly popular over the traditional cast as patients treated with CAM walkers have shown significantly less edema, tenderness, and joint stiffness after six weeks of immobilization as compared to a standard below knee cast (1). CAM walkers have incorporated rocker sole designs to accommodate deformities, limit painful joint motion, and reduce plantar pressures, shock, and shear on specific areas of the foot following a wide array of surgical procedures (2). A potential concern is the increase in heel height attributed to CAM walkers as the raised heel height on the walker side artificially creates a LLD (3). CAM walkers, occasionally worn for extended periods, can alter the gait pattern and ground reaction forces during midstance (3). Clinical sequelae from LLD include limp, low back pain, and hip instability, as well as neurological effects (4). The Evenup device was created to reduce the negative impact of the LLD on post surgical walking but there has not been any objective evaluation to date.

## METHODS

**Study Procedures:**  
Ten healthy, asymptomatic subjects (7 female, 3 male) were evaluated; see table 1. The study was approved by the Temple University Institutional Review Board and a signed consent form was obtained from all subjects prior to enrollment. A biomechanical exam included measuring the resting calcaneal stance position, forefoot to rearfoot relationship, and LLD while barefoot. Subjects were tested in three conditions, see figure 2. Subjects walked at a comfortable pace on a treadmill for 3 minutes prior to testing in order to acclimate to each condition. Results were compared with an analysis of variance (ANOVA) at a significance level of 0.05.

## Temporal and Spatial Footfall Parameters:

GaitMat™ II (E.Q. Inc., Chalfont, PA) is a system for measuring the spatial and temporal parameters of gait. A sample set of data can be found in figure 3. Support base, stance time, and gait speed were obtained at 200 Hz.

## In-Shoe Plantar Pressure:

Pedar-X (Novel, St. Paul, MN), an in-shoe plantar pressure measuring system, was used; see figures 4 and 5. Each Pedar-X in-shoe includes an array of 99 high quality capacitance sensors, collected at 50 Hz. These insoles are placed inside of the shoe, plantar to the foot, and allow for the collection of plantar pressures which can be masked during analysis to provide regionalized data.

## Activities of Daily Living:

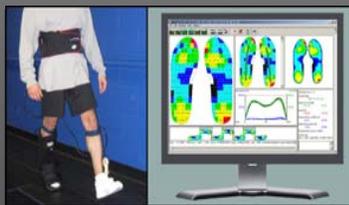
Subjects rated their level of pain during a timed 50 foot walk at comfortable speed, fast pace, and while ascending and descending five steps.



**Figure 2. Testing Conditions**  
A. SS (Control) - New Balance (NB) 574 walking shoes  
B. SEB - NB shoe with the Evenup, left and CAM walker, right  
C. SB - NB shoe, left and CAM walker, right



**Figure 3. A sample of GaitMat II data showing footprints and calculated parameters.**



**Figure 4. Subject walking with Pedar-X insoles during one of the testing conditions (left). Corresponding plantar pressure data received from subject wirelessly to computer (right).**



**Figure 5. Example depicting plantar pressures measured in each of the testing conditions.**

## RESULTS

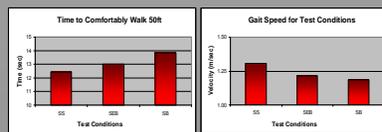
**Table 1. Characteristics of three male and seven female subjects.**

Average Age (yrs)	Average Body Weight (kg)	Average Height (cm)	Average BMI
24.6	63.82	167.5	22.7

**Table 2. Activities of daily living and gait speed results.**

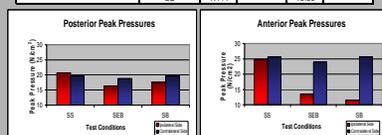
Parameter	Condition	Mean	p-value
Time to Ascend Stairs (sec)	SS	3.374	0.005†
	SEB	3.243	
	SB	4.272	
Time to Descend Stairs (sec)	SS	3.110	0.0002‡
	SEB	3.785	
	SB	5.188	
Time to Comfortably Walk 50ft (sec)	SS	12.981	0.1599†
	SEB	13.848	
	SB	17.374	
Time of Fast Walk 50ft (sec)	SS	5.872	0.0096†
	SEB	5.108	
	SB	6.108	

With significance <0.005,  
†: SS\*(SEB, SB)  
‡: (SS, SEB)\*SB  
A: SS\*(SEB)\*SB\*SS



**Table 3. Average stance time and pressure data for all subjects.**

Parameter	Condition	Mean	p-value	Mean	p-value
		Stance Time (sec)	0.688	0.723	Anterior Peak Pressures (N/cm²)
Stance Time (sec)	SS	0.683	0.0082‡	25.01	0.3882
	SEB	0.688			
	SB	0.899			
Anterior Peak Pressures (N/cm²)	SS	13.54	<0.001†	25.05	0.2291
	SEB	11.42			
	SB	20.70			
Posterior Peak Pressures (N/cm²)	SS	16.35	<0.001†	19.00	0.2291
	SEB	17.24			
	SB	17.24			



**Table 4. LLD of different testing conditions.**

Parameter	Condition	Mean	p-value
LLD (R-L), cm	SS	0.300	0.0002‡
	SEB	-0.500	
	SB	0.800	

## DISCUSSION

**Activities of daily living** showed statistical significance in the fast walk, up the stairs, down the stairs, and total stair time trials between the control condition and both of the CAM walker conditions but not between the two CAM walker conditions themselves, see table 2. Although there was not a significant difference during the comfortable paced walk in any of the conditions, the results do indicate that the CAM walker plus the Evenup device on the contralateral side more resembles the bilateral sneaker condition than the condition with just the CAM walker.

**GaitMat II**, temporal and spatial gait analysis showed that the gait speeds for the two testing conditions were significantly slower than the bilateral sneaker condition. The results can be seen in table 2. Although the two testing conditions were not significantly different from one another, the trend continued that the condition with the Evenup device was more like the control condition than the CAM walker alone. Stance time results were more like that of the control condition on the ipsilateral side; see table 3. This could indicate a greater degree of comfort and less of a need to quickly ambulate off of that area.

**Plantar pressure** analysis revealed that the anterior peak pressures were all significantly different from one another on the ipsilateral side when correcting for LLD. Slight increases in anterior peak plantar pressures were observed when using the Evenup relative to the sneaker alone with the CAM walker. This may be due to a reverse limb length that was created by the Evenup device; see table 4. The New Balance shoe thickness, although less than, was close to equal to the CAM walker to begin with. Adding the Evenup device created more of an opposite LLD. In patients with lower profile shoe gear it would be possible to add the Even up device and adjust height setting in order to appropriately equilibrate bilateral sole thicknesses. Correspondingly, posterior peak plantar pressures were decreased while wearing the Evenup compared to the CAM walker alone.

In addition, our subjects filled out a post study questionnaire. Of the ten subjects, seven indicated that they preferred wearing the Evenup along with the CAM walker, two subjects preferred the sneaker without the even up device, and one subject had no preference between the two. Several of the subjects made additional comments stating that with the Evenup device on they felt less impact, more stability, less knee and hip discomfort, and an overall ease of walking as compared to using a CAM walker without the Evenup device on the contralateral limb. None of the subjects experienced any pain during the testing.

## LIMITATIONS OF STUDY

- Only ten subjects were studied; a larger sample size would increase the power of our test.
- Only immediate effects were studied.
- A young sample population (average age of 25 years) does not demonstrate the advantages this device may have in an older population that has decreased muscle mass and more difficulty in adapting to changes in limb length.
- Plantar pressures are a function of gait speed. Future studies could record speed during pressure measurements.
- 3D kinematic data are needed to examine the effects of the limb length correction on other lower extremity joints.

## CONCLUSIONS

- Wearing the Evenup device allows for the subjects speed of gait to more closely resemble that of normal speed.
- Wearing the Evenup device on the contralateral limb affects plantar pressures on the ipsilateral limb.
- The Evenup device may be a viable supplement for patients experiencing limb lengthening sequelae.
- The Evenup device may contribute to increased compliance in patients when using a CAM walker post-surgically because of the perceived benefits of comfort and stability.
- The Evenup device is height adjustable, so the height of the boot should be considered when matching the Evenup and shoe combined height.
- It is possible that the Evenup device may cause a reverse LLD if the added height is greater than the CAM walker.
- Additional studies are needed.

## REFERENCES

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2. Brown D, et al. *Arch Phys Med Rehabil*. 2004, 85: 81-6.
3. Zhang S, et al. *Gait and Posture*. 2006, 24: 487-492.
4. Sathappan S, et al. *J Arthroplasty*. 2008, 23(2): 203-209.