# VERTICAL DISPLACEMENT OF THE CENTER OF MASS DURING SPRING-LOADED CRUTCH AMBULATION

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## INTRODUCTION

Approximately 600,000 Americans use crutches each year [1]. A relatively novel spring-loaded crutch design is now being marketed (Figure 1A). The manufacturer (Millennial Medical Inc, Logan, UT, USA) of this crutch design has speculated that because a spring located in the crutch post compresses during crutch-ground contact, crutch length decreases, and less vertical displacement of the whole-body center of mass (COM) may occur during each crutch-ground contact phase of crutch ambulation. Although this idea is somewhat intuitive, it has not yet been evaluated objectively. Decreasing vertical displacement of the COM during crutch ambulation may be important, as it could decrease mechanical work that is performed on the COM and contribute to decreased metabolic energy expenditure during crutch ambulation; increased metabolic energy expenditure is a major challenge for habitual crutch users [2].

The primary purpose of this study was to objectively evaluate the idea that COM vertical displacement during the crutch-ground contact phase of crutch ambulation is less during spring-loaded crutch ambulation, relative to traditional crutch ambulation. We formulated two hypotheses related to this purpose: (1) COM vertical displacement during crutch-ground contact would be less during spring-loaded crutch ambulation than during traditional crutch ambulation; and (2) COM vertical displacement during spring-loaded ambulation would be negatively correlated to subject body mass. The second hypothesis was based upon the premise that increased body mass would increase spring compression and further decrease COM vertical displacement during spring-loaded crutch ambulation. Additionally, in an attempt to better understand other source(s) of potential differences in COM vertical displacement, we observed several other basic kinematic variables that could influence COM vertical position during crutch ambulation; these included sagittal-plane elbow, hip, knee, and ankle joint angle.

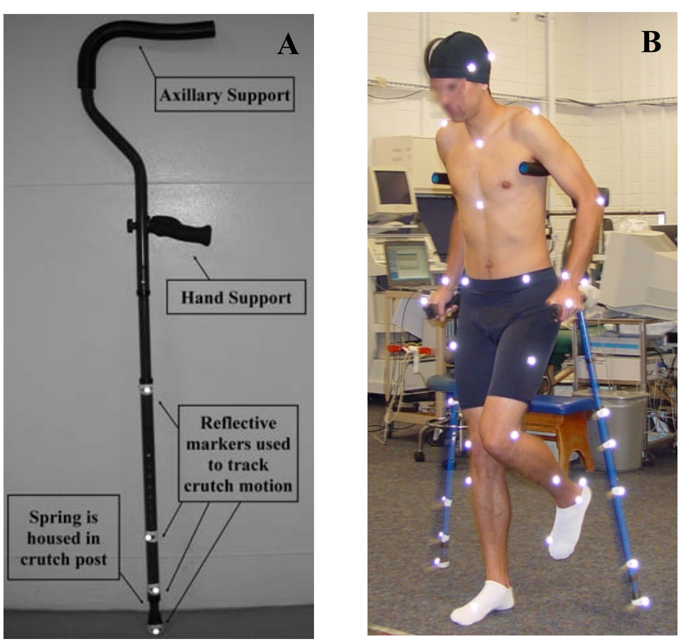


**Figure 1A.** The spring-loaded crutch design that was tested during the present study; **B.** the marker set that was used during the present study.

## METHODS

Eighteen healthy subjects (10 females; 8 males; age = 23 ± 2 yrs; height = 1.72 ± 0.10 m; mass = 68.6 ± 14.5 kg) gave informed consent and participated in this study. Subjects were fitted to crutches in a uniform manner using accepted standards. Subjects then became familiar with each crutch type by ambulating for approximately 100 meters with each crutch type. Thirty-five reflective markers were applied to each subject according to the VICON Plug-In Gait model (Figure 1B). Subjects performed three ambulation trials with each crutch type at a standardized speed (0.97 ± 0.05 m/s). The crutch order was randomized and videography (VICON, Centennial, CO, USA; 60 Hz) was used to measure the spatial position of the reflective markers. Whole-body COM position and the aforementioned joint angles were calculated using VICON Nexus software. A custom algorithm was written in Matlab to evaluate the dependent variables only during the crutch-ground contact phase of crutch ambulation. Related to Hypothesis 1, paired *t*-tests ($p$ = 0.05) were utilized to compare COM vertical displacement and joint angles between spring-loaded and traditional crutch ambulation. Significance levels for these comparisons were adjusted using the false discovery rate procedure [3]. Related to Hypothesis 2, a Pearson product moment correlation coefficient was calculated in order to evaluate a potential relationship between subject mass and vertical COM displacement.

## RESULTS AND DISCUSSION

Means, standard errors, and *p* values corresponding to the paired *t*-tests are presented in Table 1. No significant between-crutch difference existed for COM vertical displacement. Similarly, following adjustments for multiple comparisons, no significant between-crutch difference existed for any observed joint angle. No significant correlation ($r^2 = -0.37$; $p = 0.13$) was found between body mass and COM vertical displacement (Figure 2).

The data failed to support both of our hypotheses. Regarding Hypothesis 1, and contrary to previous speculation, there is no difference for COM vertical displacement between spring-loaded and traditional crutch ambulation. We did objectively observe spring compression during crutch ambulation, as was expected. However, the apparent resulting decrease of crutch length does not significantly alter the vertical displacement of the COM while it moves forward, past the crutch-ground contact location. This is important, as it indicates that similar magnitudes of mechanical work are performed on the COM during spring-loaded and traditional crutch ambulation. This observation supports metabolic data recently collected in our lab that indicated metabolic costs are similar for spring-loaded and traditional crutch ambulation. The present data also contradicted Hypotheses 2, which predicted a negative relationship between subject mass and COM vertical displacement during spring-loaded crutch ambulation. This observation further supports the notion that spring compression that occurs during spring-loaded crutch ambulation probably does not significantly influence COM vertical displacement. Perhaps an evaluation of other kinematic measures would indicate how the body compensates for the increased compliance of the spring-loaded crutch.

**Table 1.** Results from paired *t*-tests. COM$\Delta_Z$ indicates COM vertical displacement; MEA, MHA, MKA, and MAA indicate mean elbow, hip, knee, and ankle angles during crutch-ground contact.

| | Spring | Traditional | *p* |
|---|---|---|---|
| **COM$\Delta_Z$** | 2.47 ± 0.29 | 2.77 ± 0.19 | 0.24 |
| **MEA** | 37.0 ± 2.0 | 34.0 ± 1.5 | 0.02 |
| **MHA** | 24.9 ± 2.2 | 25.2 ± 2.1 | 0.75 |
| **MKA** | 50.3 ± 2.2 | 49.8 ± 2.8 | 0.72 |
| **MAA** | 0.9 ± 1.5 | 1.2 ± 1.4 | 0.81 |

## CONCLUSIONS

There is no difference in the magnitude of whole-body COM vertical displacement during spring-loaded and traditional crutch ambulation. This indicates that mechanical work performed on the COM during crutch ambulation is also similar between spring-loaded and traditional crutches. Also, there is no statistical difference between spring-loaded and traditional crutch ambulation for various sagittal-plane joint kinematics.


## ACKNOWLEDGEMENTS

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## REFERENCES


1. Russell J et al., *Cntr Disease Control Prev* 292, 1-10, 1997.
2. Fisher & Patterson, *Arch Phys Med Rehab* 62, 250-256, 1981.
3. Curran-Everett D, *Am J Physiol*, 279, R1-R8, 2000.


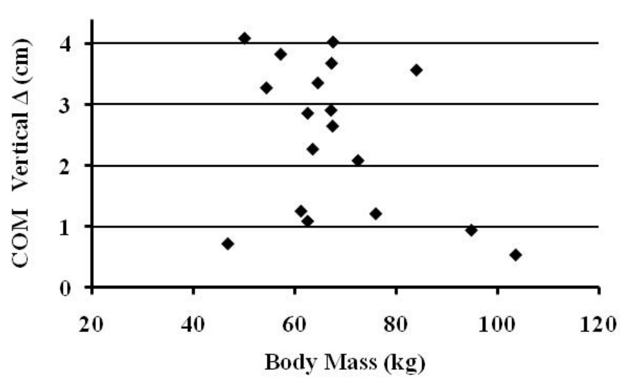


**Figure 1.** A scatter plot showing the relationship between body mass and COM vertical displacement during spring-loaded crutch ambulation.