Original Article

Center of mass with the use of smartphone during walking in healthy individuals

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Abstract. [Purpose] The purpose of this study was to measure the center of mass using a smartphone application during walking in healthy. [Subjects and Methods] Forty eight healthy participants volunteered for this study. Measurements of center of mass were obtained by gait analysis application using smartphone while subjects performed 6 meter walking test. The measured data were automatically calculated by the application, subjects performed three trial walks to get a more accurate data analysis. [Results] There were no significant differences among subjects or between genders during the three trials in the vertical and lateral displacement of COM, and the results of the Kolmogorov-Smirnov test showed no differences in vertical and lateral displacement of COM in all subjects or between genders. However, the vertical displacement of COM significantly varied in male subjects than in female subjects, but the lateral displacement of COM did not significantly differ between the male and female subjects. [Conclusion] We can use the Smartphone application to measure the COM for walking; however more studies comparing advanced technological instruments with the smartphone application are needed.

Key words: Center of mass, Smartphone application, Walk

INTRODUCTION

Center of mass (COM) is the central point on the human body1). During standing or walking, maintaining a COM within a Base of support (BOS) is an essential ability in healthy people, older adults as well as patients2, 3). Therefore, knowledge of the COM motion is one of importance for analysis or for understanding walking patterns4). Gutierrez et al.5) conducted studies using COM excursion during normal walking, while Ortega and Farley6) studied how COM affects metabolic cost during walking.

Generally, measuring COM is used with accelerometers and foot pressure systems7), kinematic models such as force plates and motion capture systems8). Among these methods, accelerometers are easy to use and provide repeatable and suitable data for clinicians9).

Recently, Jung et al.10) analyzed COM using a Samsung Galaxy S II with an Accelerometer Monitor application built for normal walking. The limitation of their study is that the application uses raw signals from an accelerometer, which indirectly shows the COM during walking. Therefore, in this study we measured COM directly using a smartphone application, to assess its feasibility in measuring walking in normal healthy subjects.

SUBJECTS AND METHODS

We enrolled 48 healthy participants (13 male and 35 female) for this study and obtained written informed consent from...
all participants following the Declaration of Helsinki principles. If subjects want to stop experiment or want to not use their data for this study, we excluded data in this study. The 48 subjects had no other musculoskeletal, cardiopulmonary, or neuromuscular disorders, and no history of any physical therapy in the last six months prior to recruitment. Table 1 describes the general characteristics of the participants. There was a significant difference between male and female subjects in the height and weight (p<0.05).

During the 6 meter walking test (6MWT), displacement of the COM was measured using gait analysis (YTA, K.K., Japan) of the smartphone application. COM data were measured with vertical and lateral displacement. The smartphone used was an iPhone 6S (Apple Inc., CA, USA) attached to the 5th lumbar vertebra and tightened with Velcro™. The date was automatically calculated by the application, and the sampling rate was 100 Hz. Subjects performed three trial walks to get a more accurate reading and reliability for data analysis.

Descriptive statistics were used to describe the participants and the independent t-test was used to determine the significance between male and female subjects in age, height, weight, and COM displacement. Repeated one-way analysis of variance (ANOVA) was used to determine the reliability among the three trials, and a Kolmogorov-Smirnov test was used to determine the normality in COM displacement. The p value was set at 0.05 for all statistical tests.

**RESULTS**

There were no significant differences among subjects or between genders during the three trials in the vertical and lateral displacement of COM (p>0.05) (Table 2).

In addition, the results of the Kolmogorov-Smirnov test showed no differences in vertical and lateral displacement of COM in all subjects or between genders (p>0.05). Lastly, the vertical displacement of COM significantly varied in male subjects than in female subjects (p<0.05), but the lateral displacement of COM did not significantly differ between the male and female subjects (p>0.05) (Table 3).
DISCUSSION

The purpose of this study was to investigate the COM directly using a smartphone application in healthy subjects. The results suggest that COM measured by this application shows consistency within three trials in both men and women. In addition, there are significant differences in displacement of the vertical COM between genders.

During three trial walking performances, there are no significant differences in displacement of the vertical and lateral COM. In addition, the displacement of COM had normality based on analysis with a Kolmogorov-Smirnov test in men and women. These results indicate that COM measured by a smartphone application had consistency and provide feasible walking data in normal subjects. Based on the data, the vertical displacement of COM is 2.98 ± 0.62 cm, and the lateral displacement of COM is 1.81 ± 0.68 cm. Generally, the vertical displacement of COM is 5 cm and the lateral displacement of COM is 4 cm[11]. However, these are based on the motion of point in the head. Orendurff et al.[12] revealed a vertical displacement of COM between 4.89 ± 1.03 cm to 2.74 ± 0.52 cm, and a lateral displacement of COM between 3.29 ± 1.29 cm to 6.99 ± 1.34 cm. This depends on the walking speed based on inverse dynamic kinematical models by a motion capture system. We measured COM based on around the 5th lumbar vertebra during walking. These differences in values are based on different measuring points with earlier studies and our study. Furthermore, our data revealed smaller values of height and weight in subject’s anthropometric data. Our results showed a difference in the vertical displacement of COM in men and women, which may be because of the differences in height and weight between men and women. Zijlstra and Hof[4] also reported that the vertical displacement of COM depends on a subject’s stride length. Hernández et al.[2] also reported differences in younger and older healthy adults. Our results reflect the different COM values in men and women seen in earlier studies and agree that the differences depend on anthropometrical and measuring methods.

In clinical situations, clinicians easily, reliably, and efficiently measure the ability of patients for the following: outcomes, progress, and prognosis for their interventions. The patients have to walk safely. Walking is a fundamental function for people in their activity of daily livings (ADLs). Therefore, based on our results, measuring COM by a smartphone application is a feasible method and easy to implement in patients, as well as in a clinical setting.

A limitation of this study was that only the Smartphone application was used, and there is no technical support for our data results. Furthermore, there is no direct comparison with the patient’s data using this application. Therefore, further studies need to compare the difference from the smartphone application for providing feasibility of Smartphone application in analyzing walking.

In conclusion, our results suggest that we can use the Smartphone application to measure the COM for walking. However more studies using and evaluating the application are needed. In addition, more studies comparing advanced technological instruments with the smartphone application are needed as well, for proof of their effectiveness.

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