A NEW METHOD FOR MEASURING SEGMENT MASS & SEGMENT CENTER OF MASS LOCATION OF HUMAN BODY

Shiming Li[1], Rong Guo[2] and Jichun Jin[3]
[1]School of Physical Education, Yantai Normal University, Yantai, China
[2]School of Foreign Language, Yantai Normal University, Yantai, China
[3]Sports Science College, Beijng Sport University, Beijing, China

The purpose of this study was to introduce a new method for measuring segment mass & segment center of mass of human body, and determine whether valid measures of segment inertial properties can be generated from using this new method. In first place, we introduced the principles of two types of instruments used in this new method, one for measuring segment moment of mass ($m_b \times r_b$), and the other for measuring segment center of mass (r_b), and then we obtained segment mass (m_b). We measured 9 subjects using the above two types of instruments, and these segments measured included one forearm-hand, one upper limb, one shank-foot and one lower limb. There is no significance discrepancy between the calculations of database provided by Xiuyuan Zheng using CT method and ours, which showed that the new method is a valid method.

KEY WORDS: segment mass, segment center of mass location, a new method

INTRODUCTION: Segment mass and segment center of mass location of human body are 2 elementary inertial parameters for kinetic analyses of human motion. In the past, the most popular approach used to estimate segment parameters has been based on data obtained from elderly male cadavers. This database is quite limited in that a small number of cadavers have been studied. Thus, the database for making inertial estimates is not representative of the subjects often under investigation in many exercise and sport biomechanics studies.
More recently, other techniques have been developed in which inertial properties are directly measured for an individual. Brooks and Jacobs (1975) used gamma mass scanning as a means of quantifying mass distribution in animal segments while Zatsiorsky and Seluyanov (1983, 1985) applied the same technique in analyzing human body segment inertial characteristics. Their results were promising and indicated that this method gave accurate measures of inertial properties.
Huang and Wu (1976) developed a technique by which tissue densities could be estimated *in vivo* using computerized tomography (CT), and they subsequently extended the use of CT technology to a consideration of mass distribution in both human and animal specimens. By first defining the boundaries of different tissues in a CT cross-section, the inertial characteristics of the individual tissues and whole segments were subsequently computed from tissue density and volume data. Xiuyuan Zheng *et al.* (1998) publicized their database of human inertial properties obtained from 100 Chinese subjects (50 male students and 50 female students) using CT. From these analyses, it is clear that both gamma mass scanning and CT represent promising approaches for estimating segment inertial parameters of human body. Nevertheless, a limitation of both techniques is that they are radiation-based, even though the radiation levels are low.
In order to avoid radioactivity in the process of measurement, we developed a new method to directly measure segment mass and segment center of mass location for an individual without radiation-based. Consequently, the purpose of this study was to determine whether valid measures of segment inertial parameters based on our new method could be generated.

METHODS: In order to measure segment mass and segment center of mass location directly for an individual, we have made two types of instruments, and one for measuring segment moment of mass, i.e. the product of segment mass multiplied by the distance from segment proximal end (axis of rotation) to the segment center of mass, the other for segment center of mass. Afterwards we integrated the above two parameters, and then we could obtain segment mass. The principles of the two instruments are as follows:
(1) Figure 1 presents principle of the instrument for segment moment of mass.

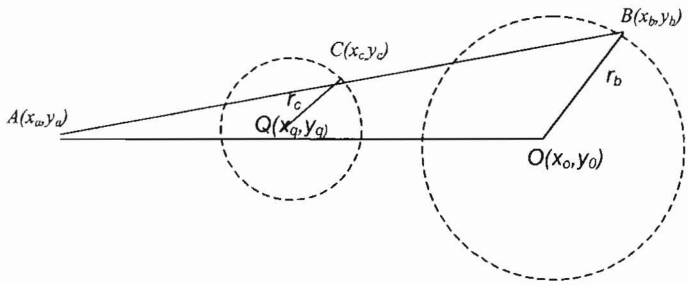

Figure 1 The principle of the instrument for measuring the segment moment of mass.

Notes: *B* represents the segment center of mass location that was measured while *O* represents the proximal end (axis of rotation) of segment, i.e. the joint center. *C* represents the center of mass of total human body while *Q* is its center of "*Q*" circle. *A* represents the center of mass of the rest which does not include the segment being measured. r_b is the distance from segment center of mass location (*B*) to the axis of rotation of segment (*O*) while r_c is the distance from *C* to *Q*.

In Figure 1, when *B*, the segment center of mass, moves along the perimeter in which *O*, the axis of rotation of segment, is the center of circle, *C* (the center of total human body) also necessarily moves along another perimeter in which *Q* is the center of circle. Based on the linkage relationship of the segment center of mass (*B*) and the center of total human body (*C*), we could obtain an equation as follows

$$m_b \cdot r_b = m_c \cdot r_c \qquad (1)$$

Where m_b is the mass of the segment being measured while m_c is the mass of total human body which may be measured by normal scale in advance, and r_b is the distance from *O* to *B*, i.e. radius of "*O*" circle, while r_c is the distance from *Q* to *C*, i.e. the radius of "*Q*" circle. We called $m_b \times r_b$ as segment moment of mass, and if we obtained the value of $m_c \times r_c$, thus we got the value of $m_b \times r_b$ based on equation (1). In order to obtain the value of $m_c \times r_c$, we let the measured segment (i.e. *B*) move to three different locations along the perimeter of "*O*" circle, and then *C* (center of total human body) also necessarily moves to three different locations along the perimeter of "*Q*" circle. By means of measuring the three different locations of *C* in which we used two-dimensional reaction board method and subsequently by means of using the equation with which the radius of "*Q*" circle (r_c) was determined by the coordinates of three different locations, we obtained the value of r_c and then $m_c \times r_c$ which equals to $m_b \times r_b$, the segment moment of mass. In fact, we wanted that the final results were m_b (segment mass) and r_b (r_b is the radius which provides the basis for determination of segment center of mass location) separately, not the product of integrating m_b with r_b into one parameter. Hence we needed the other instrument for segment center of mass that can give the value of r_b.

(2) Figure 2 presents principle of the instrument for segment center of mass location.

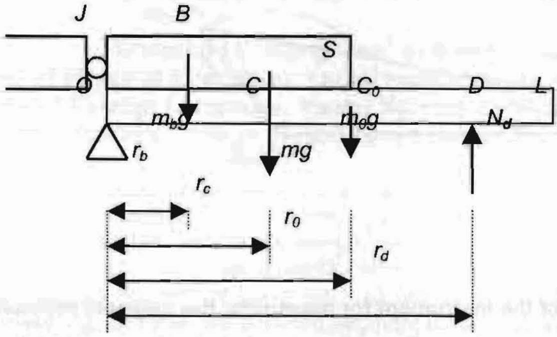

Figure 2 The principle of instrument for measuring segment center of mass location.

Notes: *S* represents the measured segment and *B* is its center of mass location while *L* represents the reaction board being positioned horizontally under the measured segment, and *O* and C_0 is its pivot and its center of mass, respectively. *D* is a moving transducer that can measure the vertical force ($\boldsymbol{N_d}$). *C* is the integrated center of mass of both the measured segment center of mass (*B*) and the reaction board center of mass (C_0). m_b and m_0 are the masses of the measured segment (*S*) and the reaction board (*L*), respectively. *m* equals m_b plus m_0. **g** is the acceleration due to gravity. r_b, r_c, r_o and r_d are the distances from *B*, *C*, C_0 and *D* to *O*, respectively, and r_b is also the radius of "*O*" circle in Figure 1. which can provide the basis for determination of the measured segment center of mass location. *J* is a joint by which can link the measured segment and the rest of human body.

In Figure 2, the measured segment (*S*) was required to place on the reaction board (*L*) statically, and we let *D* (force transducer) move towards *O* (the pivot) to search *C* (the integrated center of mass). Because at the location of *O* the board was not linked with the pivot, only on the pivot, the board would lift up and leave off the pivot when *D* arrive at *C*, and then we got r_c, (the distance from *C* to *O*) under the conditions of the board being dynamic equilibrium. In addition, the distance from C_0 to *O*, i.e. r_o, may be measured in advance, so we used the following equation to calculate r_b (the distance from *B* to *O*), i.e. the radius of "*O*" circle in Figure 1.

$$r_b \approx \frac{N_d \cdot r_c - m_0 g \cdot r_0}{N_d - m_0 g} \qquad (2)$$

Where N_d (the vertical force when *D* arrive at *C*) was measured by the force transducer, and m_0, the mass of the reaction board (*L*), was measured by normal scale beforehand, and *g* is the acceleration due to gravity.

Thus we obtained the value of the measured segment moment of mass, i.e. $m_b \times r_b$, by first instrument and the value of distance from segment center of mass (*B*) to the axis of rotation (*O*), i.e. r_b, and we combined $m_b \times r_b$ with r_b, so finally we got the segment mass and the segment center of mass location.

In all, we measured 9 subjects using the above two types of instruments, and their segments measured included one forearm-hand, one upper limb, one shank-foot and one lower limb. The criterion values of the above 4 segments were obtained by the calculation based on the database provided by Xiuyuan Zheng *et al.*

RESULTS AND DISCUSSION: Table 1 presents the results of the inertial parameters calculations based on Xiuyuan Zheng's and our methods.

Table 1 Results for Xiuyuan Zheng's and our calculations of segment mass, center of mass.

segment	M%* (mean±S.D.)		r_b%# (mean±S.D.)	
	Zheng's	ours	Zheng's	ours
Forearm-hand	1.73±0.14	1.68±0.64	44.71±3.42	43.36±7.39
Upper limb	4.46±0.22	4.65±1.28	39.55±0.95	41.94±2.18
Shank-foot	5.73±0.31	6.16±0.88	47.25±5.02	9.40±1.75
Lower limb	19.87±0.61	19.14±2.78	35.38±4.51	36.14±2.51

*M% is the percentage of total mass of human body.
#r_b% is the percentage of segment length from the proximal end.

Table 1 showed that there was no significant discrepancy in both M% (the percentage of total mass of human body) and r_b% (the percentage of segment length from the proximal end) between Xiuyuan Zheng's calculations and our calculations, and which demonstrated that our method was a valid measures.

CONCLUSIONS: In this study, we introduced the principles of two types of instruments for measuring segment mass and segment center of mass location of human body. By comparing the results of calculations based on Xiuyuan Zheng's and our methods, it was concluded that our method represents a promising technique for generating valid measures of segment mass as well as segment center of mass.

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