Estimation of Center of Gravity Obtained from 3D Whole Body Scanning Anthropometry Method

Noriko HAKAMADA[a], Kazuo FUNATO[b]
[a] Nippon Sport Science University, Tokyo, Japan;
[b] Graduate School of Health and Sport Science, Nippon Sport Science University, Tokyo, Japan

Abstract

Introduction: In the past, body segmental volume was measured from various methods as immersion method, mathematical model, photogrammetric, have been used for various research in biomechanics. As for the three dimensional anthropometry how there are a whole body volume and each segment volumes, possibility of estimation of various body segment parameter will be shown. Purpose of this study was estimated center of mass using three dimensional anthropometry.

Methods: The subjects were 6 males (Age：22.3±1.1 years, body height: 172.5±5.9cm, body mass: 67.2±2.5kg) participated in this study. We used Body line scanner (BLS: Hamamatsu Photonics KK) for 3D Whole body anthropometry. Subjects were measured a whole body volume using BLS. Scanning data obtained from BLS was distributed 14 parts of each segmental volumes using anatomical randmarkpoint, be calculated each segmental volumes. For the definition of each segment were used from C.E.Clauser,1969. Center of each segmental mass (SCOM) was calculated from each segmental volume. Segment mass (SM) was calculated using each segment density which from preceding study. Center of gravity (COG_{ABS}) and COG_{REL} (center of gravity expressed as a percentage of the body height) was calculated from SCOM and SM of each segment. For the measurement of the COG_{ABS} and COG_{REL}, the reaction board method was employed. The reaction board consisted of a rigid board (180×91.5×2.5cm) mounted on a scale. COG_{ABS} and COG_{REL} were compared from each method that calculated from reaction board , BLS and predicted value from C.E.Clauser,1969 , and calculated %Difference.

Results and Discussion: The whole body mass that we estimated using BLS compared with body weight, the difference was under 1.5%. %difference of COG_{ABS} and COG_{REL} (BLS and a measurement) were 2.9±0.9%, and the BLS showed lower than measurement (measured : COG_{ABS} ＝97.2±3.6cm, COG_{REL}＝56.6±0.5%, BLS : COG_{ABS}＝94.4±3.0cm, COG_{REL}＝54.9±0.5%). In addition, the predicted value showed higher than a measurement (predicted value：COG_{ABS}＝100.1±3.5cm, COG_{REL}＝58.3±0.6%).

Conclusion: It was suggested that We can estimate COG which we estimated from segment mass and center of volume with an measured and a difference of 2.9% .

Keywords: 3d whole body scanning anthropometry, segmental volume, center of mass

1. Introduction

Measurement and/or estimation of body center of gravity (COG) are one of the important first steps in the biomechanical analysis of movement. The reaction board method is a direct measurement of COG. COG can be calculate from body segment parameters which were conventionally measured by water displacement method [1,2,3], photogrammetric method [4] and geometrical modeling method [5]. These parameters are normally derived from predictive equations based on data from cadavers or living subjects. Applying predictive equations to populations other than that from which they are derived is likely to cause large errors in estimation [6]. These errors might have a tendency to be larger in the groups such as children, athletes, and obese subjects which are not likely to have segmental shapes and body proportions to those of the general population. Using the three dimensional whole body scanning provides a possibility for the estimation of various body segment parameters. Indicating the subject specific body segment parameters will be great values in the field of not only sports sciences but also in health sciences. The purposes of this study were to estimate center of mass (COG) using 3D whole body scanning anthropometry (BLS) and to compare body center of gravity calculated from BLS with directly measured and a previous study C. E. Clauser, 1969.

2. Method

2.1. Estimation of COG_{ABS} and COG_{REL} using 3D Whole Body Scanning Anthropometry Method (BLS)

The 3D whole body scanning anthropometry method was undertaken by introducing Body Line Scanner (Hamamatsu Photonics KK.) . Figure 1 shows the framework of laser beam measurement system, and example of scanning data was shown in Figure 2.

Fig.1. The framework of laser beam measurement system.

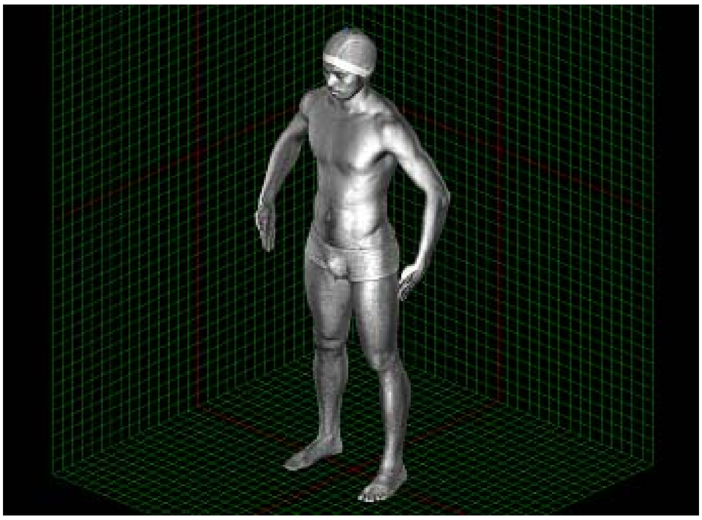

Fig.2. Example of scanning data.

As for as BLS scanning, the time needed for one measurement was 5 to 10 sec, interval of scanning was 2.5mm in the vertical direction and 1mm in the horizontal direction and all scanning data were about 400,000－700,000 points.

Whole body volume and each segmental volume were measured by analyzing the reconstructed polygon data as shown in Figure 3, in which dissection of each segment was indicated and whole body scanning data was divided into 14 segments in the same manner as the previous study by C. E. Clauser according to 72 anatomical landmark points. Each segmental volume was determined by specially programmed software. Figure 4 shows example of right thigh segment.

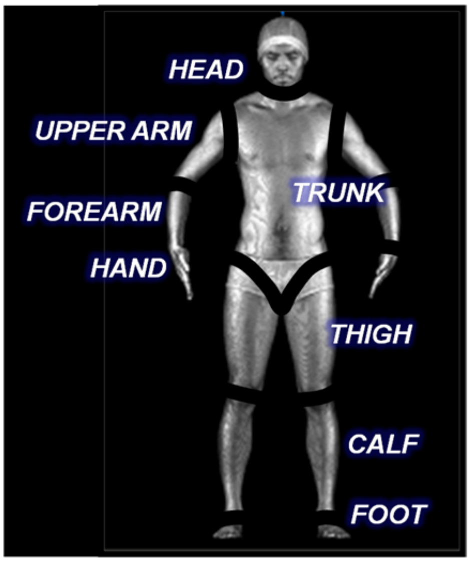

Fig.3. Definition of each segment.

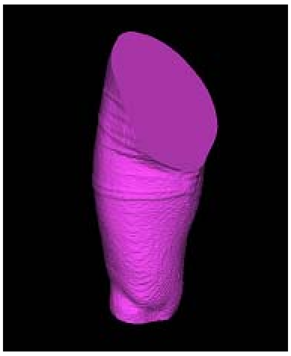

Fig.4. Example of right thigh segment.

Calculating segment mass (SM) and center of mass location from each segmental volume (SCOM) , requires estimates of density distribution at the body and segmental level. The density profile within each segment was assumed to be homogeneous, we used average segment density obtained from previous study C. E. Clauser. Table 1 showed the density of each segment as determined by Clauser. However, using an average segmental density can produce errors as within each segment there are variations in density. Therefore, using average segmental density does not truly calculate center of mass but center of volume. Thus, Centre of volume was calculated for each segment. Figure 5 showed an example of COM location in right thigh.
We calculated the absolute height of COG (COG_{ABS}) and height of COG relative to body height (COM_{REL}) using segment mass and center of segment mass in the standing posture.

Table.1. Density of each segment obtained from C.E.Clauser,1969 (unit=kg/ℓ).

HEAD	TRUNK	UPPERARM	FOREARM	HAND	THIGH	CALF	FOOT
1.070	1.019	1.056	1.098	1.109	1.044	1.085	1.084

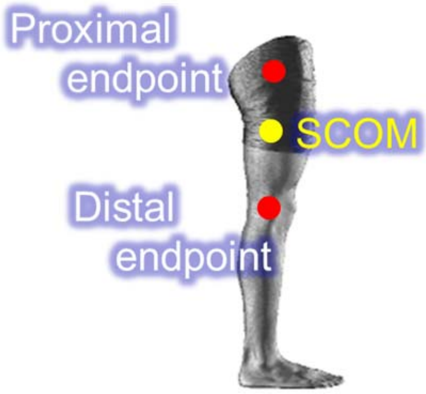

Fig.5. Example of SCOM location in right thigh.

2.2. Direct measurements of COG_{ABS} and COG_{REL} (DM)

Direct method for measuring COG was performed by using a reaction rigid board. The reaction board consisted of a rigid board mounted on two scales with a pivot point at both sides (Figure 6). Measurements were done while subjects were lying on the board in the same posture as the BLS method. We measured body weight at scale A and B, and calculated the location of COG using rate of scale A and B.

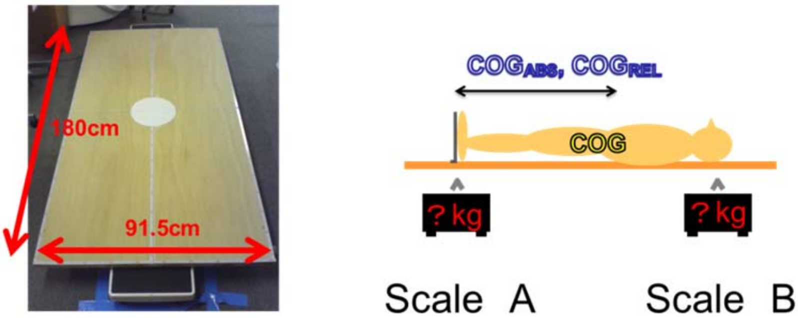

Fig.6. Reaction board method.

2.3. Subject and statistical analysis

6 males participated in this study. Age, body height and weight are shown in table2. Segmental mass and location of center of segmental mass were compared using t-test. And absolute and relative COM obtained from BLS, DM and previous study were compared using one way ANOVA , Tukey-Kramer HSD test and %Difference. The calculation of %Difference is shown in the following equation (1).

$$\%Difference = DM - (BLS\ or\ previous\ study) / DM \times 100 \qquad (1)$$

Table.2. Age, body height and weight of the subjects.

	n	Age (yrs)	Height (cm)	Weight (kg)
Male	6	22.3±1.1	172.5±5.9	67.2±2.5

3. Results

Table 3 showed segment mass relative to body mass (%SV) obtained from BLS and previous study (C.E.Clauser,1969) .%SV was almost the same for all segments between BLS and Clauser's study. However, the segment mass for the trunk calculated using BLS was significantly lower than segment mass calculated from Clauser's study. On the other hand, the mass of the thigh was significantly higher using BLS method than in Clauser's study. Table 4 showed location of center of segment mass relative to segment length (%SCOM) obtained from BLS as well as the same data in the previous study (C.E.Clauser,1969). %SCOM was almost the same for all segments. However, for the trunk region, the center of volume calculated from BLS was about 6% lower than in Clauser's study.
Table 5 showed comparison of COM and %COM obtained from BLS and DM in the direct measurement. ALL subject had a tendency to be lower in height of COM obtained from BLS method compared to the DM. These difference were an average of 2.9%
Table 6 showed COM and %COM obtained from BLS, DM and C. E. Clauser's anthropometric values. Table 6 summarized the results of the average and standard deviation from each method In the %COM, there were significant differences between all methods ($p<0.001$). %COM obtained from Clauser's anthropometric values were relatively higher compare to the present values.

Table.3. Segment mass relative to body mass obtained from BLS and previous study (C.E.Clauser,1969).

	BLS			Previous Study	
	MEAN	S.D.		MEAN	S.D.
Head+Neck	7.24	0.42		7.28	0.59
Trunk	43.50	1.06	*	50.70	2.06
UpperArm	2.71	0.17		2.63	0.22
ForeArm	1.69	0.12		1.61	0.15
Hand	0.61	0.06	*	0.65	0.08
Thigh	13.35	0.62	***	10.27	0.82
Shank	5.00	0.18	***	4.33	0.36
Foot	1.26	0.09	***	1.47	0.10

*:$p<0.05$, ***:$p<0.001$ Unit = %

Table.4. Location of center of segment mass relative to segment length obtained from BLS and location of center of mass relative to segment length obtained from previous study (C.E.Clauser,1969)

	BLS			Previous Study	
	MEAN	S.D.		MEAN	S.D.
Head +Neck	49.5	1.3	*	46.4	0.5
Trunk	31.9	3.8	*	38.0	1.6
UpperArm	51.3	1.1		51.3	2.7
ForeArm	42.6	1.4	***	39.0	2.1
Thigh	36.1	2.4		37.2	1.7
Shank	33.6	1.3	***	37.1	1.3
Foot (heel)	50.7	3.5	***	44.9	1.6

*:$p<0.05$, ***:$p<0.001$ Unit = %

Table.5. Comparison of COGABS and COGREL obtained from BLS and DM.

Sub.	BLS		DM		%Diff.
	COG_{ABS} (cm)	COG_{REL} (%)	COG_{ABS} (cm)	COG_{REL} (%)	
1	94.1	55.0	97.2	56.8	3.2
2	93.9	55.6	96.2	57.0	2.4
3	90.9	55.1	93.7	56.8	3.0
4	98.4	54.3	103.0	56.8	4.4
5	91.7	54.4	93.7	55.6	2.2
6	97.3	55.2	99.4	56.4	2.1
Mean	94.4	54.9	97.2	56.6	2.9
SD	3.0	0.5	3.6	0.5	0.9

Table.6. COG_{ABS} and COG_{REL} obtained from BLS, DM and C.E.Clauser's anthropometric values.

		BLS		DM		C.E. Clauser※	
	Unit	Mean	SD	Mean	SD	Mean	SD
COG_{ABS}	cm	94.4	3.0	97.2	3.6	100.1	3.5
COG_{REL}	%	54.9	0.5	56.6	0.5	58.3	0.6

$p<0.001$ $p<0.001$

$p<0.001$

4. Discussion

The goal of this study was to estimate of center of gravity in living humans by BLS scanning. By comparing body center of gravity calculated from BLS with directly measured and a Clauser's study, COG_{ABS} and COG_{REL} obtained from BLS were lower than the data from directly measured and estimated value from previous study (C.E.Clauser,1969). Differences in COG_{ABS} and COG_{REL} obtained from 3D whole body scanning anthropometry and directly measured were within 2.9%.

One of the factors of this error was estimated error of the segment mass. Previous study described that different segment definitions were used in cadaver studies [7]. However, this study reduced errors as much as possible by using segment boundaries definitions as much as same manner as Caluser's study. These errors may have occurred by subject's properties, race, or age.

Another factor of errors was influence of segment COM. In the cadaver's study, segment COM was located using balance plate [1, 2]. However, in the present study, segment COM was estimated using segment center of volume, because the inertial properties assumed of uniform segment density. Therefore it was suggested that large error was occurred in the trunk region that had many tissues including bone, muscle, fat and another soft tissue. Furthermore, density distribution in a segment might be taken in considerations for particular in trunk region.

5. Conclusion

Body center of gravity could be estimated using three dimensional whole body scanning with the accuracy of estimation within 2.9%. However special attention should be considered for the COM location in trunk segment.

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