Journal of Applied Biomechanics, 2018, 34, 232-235
https://doi.org/10.1123/jab.2016-0319

Human Kinetics
TECHNICAL NOTE

Effect of Trunk Segment Boundary Definitions on Frontal Plane Segment Inertial Calculations

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When defining trunk body segment parameters, such as segment length, mass, center of mass location, and radius of gyration, it is necessary to understand and define consistent, anatomically relevant segment boundaries. In addition to the differences in reported trunk parameters due to different data collection and analysis methods (such as cadaver studies and imaging methods), many previous publications have also used differing definitions of the trunk segment. The objective of this study was to determine the effect of differences in trunk segment definitions and obesity on the calculated mass, center of mass, and radius of gyration using dual-energy X-ray absorptiometry anthropometry calculations. Twenty-three participants were recruited in normal weight and morbidly obese body mass index categories. A frontal plane dual-energy X-ray absorptiometry scan was taken of each participant, and 3 trunk segment delineations used by Chambers, de Leva, and Zatsiorsky were used to calculate the trunk parameters. The results showed statistically significant effects of segmentation definition and obesity on the trunk parameters calculated. Because of the potential impacts on static modeling and inverse dynamics calculations, it is important to determine which trunk segmentations are most appropriate for specific applications and to account for the impact of obesity within individuals.

Keywords: inertial parameters, anthropometry, obesity

Body segment parameters (BSPs), such as segment length, mass, center of mass (COM), and radius of gyration, are commonly used as inputs in ergonomic applications,[1] as well as biomechanical models used to estimate the risk of musculoskeletal injuries during lifting and gait.[2–5] Specific applications of these parameters include 3-D static strength prediction modeling and inverse dynamics modeling, both of which have been shown to be sensitive to BSP inputs,[1,6–13] with errors as high as 60% resulting from inverse dynamics gait analysis.[12,13] Whole-body COM computations mostly affected by the COM location of large body segments, such as the trunk and the thigh, are also important in postural control research using whole-body COM movements as a measure of balance performance.[14]

There are a number of published regression models allowing the research and clinical communities to predict parameters. These models often use different trunk segment boundaries[12,15] and may exclude regions of the hips based on trunk and thigh segment definitions.[16] These regions may be significant in obese adults. This is of particular concern in light of previous work demonstrating that age and body mass index (BMI) influence parameters, particularly in large segments such as the thigh and trunk.[16]

Thus, the current study, using in vivo dual-energy X-ray absorptiometry (DXA) data, aims to objectively quantify the impact of trunk segmentation method on trunk BSPs in normal weight and morbidly obese young adults. Three common segmentation methods are used to define the trunk segments, namely Zatsiorsky,[17] de Leva,[15] and Chambers.[16] It is hypothesized that the difference in parameters between the 3 predictive methods will be greater in obese young adults than in normal size young adults.

Methods

After giving written informed consent, 23 participants (11 females; mean [SD]: age = 30.3 [6.2] y) participated in a single visit for this study. The University of Pittsburgh Institutional Review Board approved the study. Participants were recruited according to BMI, so that the final sample consisted of 6 normal weight ($18.5\ kg{\cdot}m^{-2} \le BMI < 25.0\ kg{\cdot}m^{-2}$) males (mass = 68.7 [5.7] kg and height = 1.76 [0.05] m); 6 normal weight females (mass = 56.3 [4.4] kg and height = 1.63 [0.07] m); 6 morbidly obese ($BMI \ge 40\ kg{\cdot}m^{-2}$) males (mass = 138.0 [12.6] kg and height = 1.78 [0.04] m); and 5 morbidly obese females (mass = 125.3 [16.9] kg and height = 1.65 [0.08] m). First, stature and body mass were collected from each participant in order to confirm BMI, and then each eligible participant was scanned using a Hologic Discovery DXA System (Hologic, Bedford, MA) to collect a frontal plane, full body image. Anatomical landmarks were used to determine the trunk boundaries from the DXA scan images according to definitions used by Zatsiorsky,[17] de Leva,[15] and Chambers[16] (Figure 1). All scans were analyzed by the same researcher, who had proven to be consistent in boundary locations according to a previous reliability analysis, with an average difference in calculated segment parameters of less than 2%.

The primary difference between the 3 definitions is the inferior border between the trunk and the superior border of the thigh segment (Figure 1). Both the Zatsiorsky and de Leva definitions use the hip segmentation plane, which is perpendicular to the frontal plane, through the anterior superior iliac spine, 37° from the sagittal plane. The Zatsiorsky inferior boundary is the intersection of the hip segmentation planes, while the de Leva inferior boundary is a plane perpendicular to the frontal plane through the mid hip joint center. Like the de Leva segmentation, the Chambers definition has an inferior boundary through the mid hip joint center; however, the inferior-lateral border is based on a plane through each greater trochanter and inferior ischial tuberosity.

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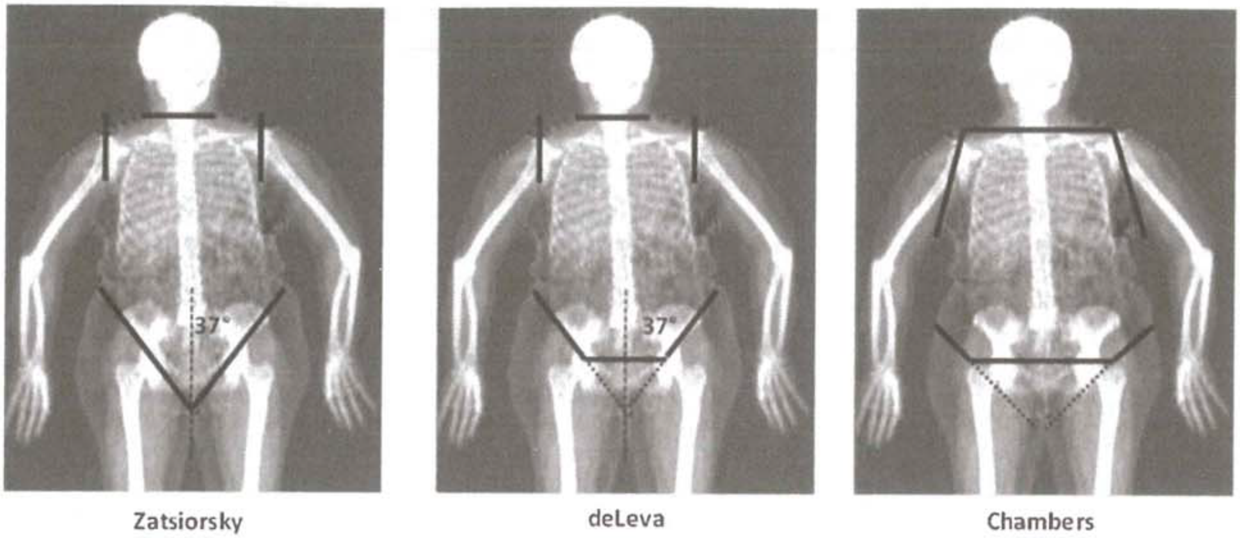

Figure 1 — Trunk segment boundaries for Zatsiorsky, de Leva, and Chambers.

On the superior end of the trunk segment, both Zatsiorsky and de Leva use a transverse plane through the seventh cervical vertebra, while Chambers uses a transverse plane through the acromion midpoint (Figure 1). In order to separate the arms from the torso, Zatsiorsky and de Leva use planes through the shoulder joint centers parallel to the sagittal plane, while Chambers uses planes perpendicular to the frontal plane through the acromion and axilla.

To determine the in vivo trunk parameters, including trunk segment mass, COM, and radius of gyration about the superior–inferior axis, the DXA scan of the trunk was divided into slices covering the width of the segment, with a height of 2 to 3 pixels, corresponding to a thickness of 2.6 to 3.9 cm tall.[16] The DXA scan analysis determined the mass of each slice and used these masses and known slice heights to calculate the segment COM and radius of gyration as a percentage of segment length. Segment mass was expressed as a percentage of total body mass.

A linear regression analysis was used to determine the impact of segmentation method (Zatsiorsky/de Leva/Chambers), BMI (normal weight/morbidly obese), gender (male/female), as well as their first-order interactions on the torso mass, COM, and radius of gyration. Subject was included as a random factor. Post hoc Tukey HSD tests and Student's t tests were performed when significant effects were observed. Significance was set at $\alpha = .05$.

Results

The results showed multiple significant effects of gender, obesity, and trunk definition method on the trunk-normalized mass, COM, and radius of gyration (Tables 1 and 2).

The analysis for trunk mass as a percentage of body mass (%M) showed significant effects of obesity ($P = .01$), method ($P < .001$) and as expected, gender ($P = .02$). The interaction effects of these fixed factors on normalized trunk mass were not statistically significant. Post hoc Tukey HSD tests showed that between trunk definition methods, Zatsiorsky had significantly higher mass (46.9% M) than Chambers and de Leva (42.8% and 42.2% M, respectively), with no significant difference between Chambers and de Leva. Post hoc t tests showed that males had significantly higher trunk masses than females (44.9% vs 43.1% M), and the morbidly obese group had significantly greater trunk masses (45.1% vs 42.8% M).

Gender ($P < .001$), method ($P < .001$), and the interaction of obesity and method ($P = .001$) had significant effects on the trunk normalized COM location. A post hoc Tukey HSD test showed significant differences between the 3 methods (Figure 2), with de Leva being the most distal (62.8% length), followed by Chambers (53.8% length), then Zatsiorsky (46.8% length). Females showed more distally located COMs than males (55.4% vs 53.6% length).

Obesity ($P < .001$), method ($P < .001$), and the interaction of method and gender ($P < .001$) had significant effects on the trunk normalized radius of gyration location about the COM, along the superior–inferior axis. The normal weight group had a larger radius of gyration value than the morbidly obese (26.7% vs 25.3% length), indicating that the morbidly obese group has more trunk mass concentrated around the COM than the normal weight group. Between methods (Figure 3), Chambers had the largest radius of gyration value (27.7% length), followed by de Leva (25.8% length) and Zatsiorsky (24.5% length). Within the de Leva method, a significant difference was observed between genders, with males having larger radius of gyration values than females (26.3% vs 25.3% length).

Discussion

The results demonstrated significant differences in commonly used anthropometric parameters within the trunk due to the specific segmentation method used, and these differences are challenging to control for as they depend on obesity, gender, and perhaps other body shapes. Although previous work has shown differences in anthropometry due to gender and obesity,[16] as well as differences between parameter calculation methods,[2,18] no studies have examined the specific effect of different segment definitions on parameter calculations, using the same calculation method. These findings are relevant because there is no single definition used for determining trunk segment parameters in the literature and clinical community. In addition, these results indicate that when comparing

Table 1 Mean Values for Each Parameter by Obesity Group, Gender, Gender Within Obesity Group, and Total Mean for the Method for Each Parameter

	NW	MO	All
Mass (%M)			
Zatsiorsky			
Male	46.5 (0.9)	49.6 (0.8)	48.0 (0.7)
Female	45.6 (0.2)	46.2 (0.3)	45.9 (0.2)
All	46.0 (0.4)	48.0 (0.7)	46.9 (0.3)
de Leva			
Male	40.8 (0.5)	45.3 (1.0)	43.1 (0.9)
Female	40.5 (0.6)	42.1 (0.5)	41.3 (0.5)
All	40.6 (0.4)	43.8 (0.8)	42.2 (0.5)
Chambers			
Male	41.9 (0.9)	45.1 (1.8)	43.5 (1.1)
Female	41.8 (0.4)	42.3 (0.5)	42.0 (0.3)
All	41.9 (0.5)	43.8 (1.1)	42.8 (0.6)
Center of mass (%length)			
Zatsiorsky			
Male	46.2 (0.6)	45.5 (0.2)	45.8 (0.3)
Female	48.5 (0.3)	47.1 (0.3)	47.9 (0.3)
All	47.3 (0.5)	46.2 (0.3)	46.8 (0.3)
de Leva			
Male	63.0 (0.4)	60.9 (0.4)	62.0 (0.4)
Female	64.1 (1.1)	63.3 (0.7)	63.7 (0.7)
All	63.6 (0.6)	62.0 (0.5)	62.8 (0.4)
Chambers			
Male	52.2 (0.3)	53.8 (0.4)	53.0 (0.3)
Female	54.6 (0.2)	54.5 (0.4)	54.6 (0.2)
All	53.4 (0.4)	54.1 (0.3)	53.7 (0.3)
Radius of gyration (%length)			
Zatsiorsky			
Male	25.2 (0.1)	23.6 (0.1)	24.4 (0.3)
Female	25.4 (0.2)	24.0 (0.1)	24.7 (0.3)
All	25.3 (0.1)	23.8 (0.1)	24.6 (0.2)
de Leva			
Male	26.7 (0.2)	25.8 (0.2)	26.3 (0.2)
Female	26.0 (0.3)	24.7 (0.2)	25.4 (0.3)
All	26.3 (0.2)	25.3 (0.2)	25.9 (0.2)
Chambers			
Male	28.2 (0.2)	26.9 (0.5)	27.6 (0.3)
Female	28.6 (0.2)	26.8 (0.1)	27.8 (0.3)
All	28.4 (0.1)	26.9 (0.2)	27.7 (0.2)

Abbreviations: M, body mass; MO, morbidly obese; NW, normal weight. Note: Values are given as mean (SE).

results between different parameter calculation methods, it is important to also consider the specific boundaries of each method so that the comparison is actually considering the exact same segment.

Of the 3 methods used in this study, the optimal segmentation method would likely be dependent on the specific application used. For example, the method defined by Chambers[16]

Table 2 *P* values for All Predictors and Interactions for Each Parameter

Predictor	Mass (%M)	COM (%length)	Radius of gyration (%length)
Gender	$P = .02$	$P < .001$	$P > .1$
BMI category	$P = .01$	$P > .1$	$P < .001$
Method	$P < .001$	$P < .001$	$P < .001$
BMI category × gender	$P = .07$	$P > .5$	$P > .1$
Method × gender	$P > .5$	$P > .5$	$P < .001$
BMI category × method	$P > .1$	$P = .001$	$P > .1$

Abbreviations: BMI, body mass index; COM, center of mass.

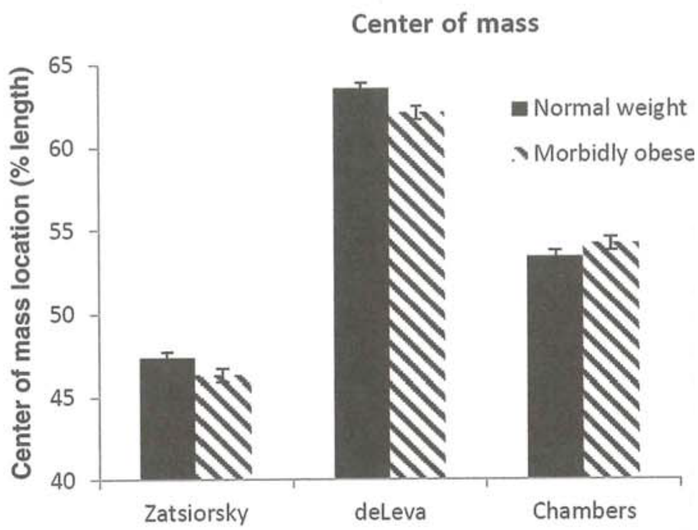

Figure 2 — Center of mass values as percent segment length, by method. Values are shown as mean (SE). Higher values indicate more distal locations.

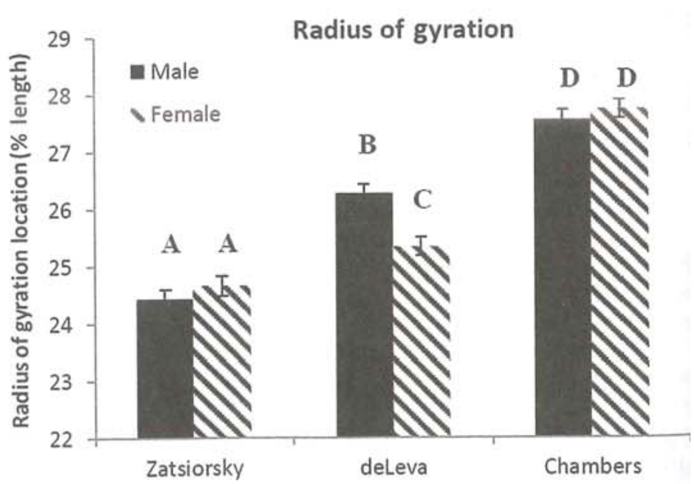

Figure 3 — Radius of gyration values as percent segment length, by method. Values are shown as mean (SE). Different letters indicate significant differences between groups.

would provide the best subject-specific measures, due to the hip segmentation boundary being defined by each individual's anatomy, instead of the predefined 37° angle used in the other 2 definitions. The Chambers method would also be most appropriate in inverse dynamics calculations due to the thigh-torso segmentation being more applicable to hip joint rotation. The Zatsiorsky and de Leva methods may be more desirable for orthopedic applications and for static or seated analyses. In these applications, accounting for minor variations in individual anatomy is not as important as ensuring that all trunk segments have the same shape at the shoulder and hip delineations. In addition, smaller differences between the individual and the model used will lead to smaller errors in calculations due to the lack of dynamic movement.

There were a few limitations in this study, primarily due to the nature of the DXA scan performed. First, only frontal plane scans were collected, so the COM and radius of gyration values provided are only along the superior–inferior axis and do not provide any insight into the location in the anterior–posterior or medial–lateral directions. Second, all participants were lying flat instead of standing upright; thus, small shifts in mass locations likely occurred, introducing potential errors in the computation of the DXA parameters (lying flat vs standing). The final main limitation is due to the sample size used. As the participants were selected based on age and BMI from a larger study, these results may not be fully representative for the population's age and obesity ranges; however, they still indicate the importance of selecting appropriate trunk segment definitions based on the applications.

The way the trunk and other segments are defined may impact inverse dynamic and static analysis results, and the specific definitions may be dependent on the body shape and anatomy of the population of interest. Special caution should be given to which body segment parameter determination method is used to calculate anthropometric data.

Acknowledgment

There are no conflicts of interest to report. This study was funded by the National Institute for Occupational Safety and Health (NIOSH; grant no. R01 OH010106).

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