# *FINAL PROGRESS REPORT*

Obesity and Body Segment Parameters in Working Adults
NIOSH 1 R01 OH010106
November 24, 2017

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# I. List of Terms and Abbreviations

| Abbreviation | Definition |
|---|---|
| BMI | Body mass index |
| BSP | Body segment parameter |
| COM | Center of mass |
| DXA | Dual-energy X-ray absorptiometry |

# II. Abstract

Sources of anthropometric data, specifically body segment inertial parameters, are of critical importance in ergonomics and occupational biomechanics. Current models predicting such anthropometric variables are developed based on data collected in normal-weight young adults. Yet, over 60% of all US workers are either overweight or obese and this obesity epidemic worsens with increasing age with more than 75% of workers over the age of 60 years old being overweight or obese. Thus, there is a need to generate new models to predict body segment parameters that better reflect the working population. In this project, we developped new datasets of body segment parameters that include body mass index (BMI) as a factor across the age span of working adults using Dual Energy X-Ray Absorption (DXA) methods. More specifically, our goal in this project was two-fold: (1) quantify the impact of obesity on body segment parameters in full-time workers aged 21 to 70 years old (Aim #1), and (2) develop BMI-specific regression models for the prediction of body segment parameters in the same population (Aim #2).

To achieve these aims, full-time workers between the ages of 21 and 70 years old were recruited for participation in this project. They were asked to come in for one visit. During this visit, a whole-body DXA scan was collected to derive in-vivo measures of body segment parameters. Body measurements were also collected. Standard multivariate regression models were used to achieve the aims of the proposed project.

In Aim #1, the results indicate that there are several statistically and practically significant linear and quadratic effects of age, BMI, and the interaction between age and BMI on a number of BSPs in the working male and female population. Thus, it is important to consider BMI and age effects when deriving BSPs in men and women. In Aim 2, the findings indicate that the accuracy of BSPs predictions can be significantly improved (14-47%) by considering body shape, i.e. including key body measurements relevant to the BSP of interest in the prediction models.

In summary, the proposed project addressed a gap in the ergonomics and occupational biomechanics litterature by developing validated models that accurately predict body segment parameters in working adults, taking into account body mass, age, gender and body shape.

# III. Section 1: Key Findings, Translation & Research Outcomes/Impact

## A. Significant or Key Findings

In Aim #1, the results indicate that there are a number of statistically and practically significant linear and quadratic effects of age, BMI, and the interaction between age and BMI on several BSPs in the working male and female population.

In Aim 2, the findings indicate that the accuracy of BSPs predictions can be significantly improved (14-47%) by considering body shape, i.e. including key body measurements relevant to the BSP of interest in the prediction models.

## B. Translation of Findings

Findings in Aim 1 suggest that it is important to consider BMI and age effects when deriving BSPs in adult male and female workers.

Prediction models generated in this project will improve the estimates of BSPs, by using BMI, age and key anthropometric body measurements.

## C. Research Outcomes/Impact

Intermediate outcome: In this project, we quantified the impact of obesity on body segment parameters (BSPs). BSPs are required in occupational biomechanics to estimate stresses and loads on the body and thus to predict the risk of musculoskeletal injuries on the body

End outcome: If BSPs prediction models developed in this project are used, we believe the assessment of the risk of musculoskeletal injuries in obese workers will be more accurate.

# IV. Section 2: Scientific Report

## A. Background

Body segment parameters (BSPs), including the length, mass, center of mass, and radius of gyration of body parts, are used in many ergonomic applications, including the design of tools, protective clothing, equipment and workstations [1]. BSPs are also necessary to develop biomechanical tools and models required to understand and to prevent musculoskeletal injuries while performing occupational activities like lifting, locomotion, and falling [2-5]. These parameters are typically estimated using anthropometric models based upon data collected from normal-weight young adults, however, they do not accurately represent the wide range of body mass index (BMI) and age across the working American population, indicating the need for new, accurate BSP data sets.

Some of the specific applications utilizing BSPs are the 3D Static Strength Prediction Model, and inverse dynamics calculations. Both of these models can be used to calculate joint forces and moments during a specified task, as well as determine the fraction of the population capable of safely completing a task. These types of modeling use measured inputs such as subject stature and mass, applied forces, and positioning, as well as any dynamic data in the case of inverse dynamics modeling. Additionally, they also use assumed inputs such as mass distribution and individual anthropometry, which may not be representative of individuals in the workplace. This can lead to errors in the outputs of static modeling due to inaccurate segment masses and center of mass [6]. Inverse dynamics models, specifically those calculating L5/S1 joint loading and related injury risk, have been shown to be sensitive to parameter estimations such as center of mass position, joint rotation center location, length, and mass [7-9]. Other dynamic analyses, such as those used for knee and hip kinetic calculations during gait produce varying results between different standard anthropometry sets in normal and overweight adults, with deviations as high as 60% [10-11]. Such large differences in calculated values can greatly decrease the accuracy of predicted injury risk during specific tasks, and indicate that more accurate, representative sets of BSP estimation are needed.

Some of the previous BSP sets have been estimated with regression equations from data collected in cadaver studies [12-13], imaging techniques [14], and geometric modeling of the body [15]. Between these different methods, there are differences in BSP predictions as high as 40% [10], with minimal validation of the predicted parameters. Additionally, data used to predict these BSPs are often collected from healthy normal weight adults, and do not account for differences in age, physical fitness and body shape, or obesity status [2,5], meaning that they are likely not representative of the American workforce.

Previous investigation of traditional regression equations for BSPs has shown that they are inaccurate for older adults, with the errors being functions of gender and mass distribution, and vary with the type of parameter of interest [16]. In large segments, such as the torso and thigh, parameters in older adults differ by 20-50% when compared to the deLeva predicted equations [16], which can lead to errors in L5/S1 peak moment calculations of 15-25%.

There is a need to develop more accurate BSP models that better reflect the diversity of the American workforce, particularly as related to weight and age. Over 60% of US workers are either overweight ($25.0 \leq BMI < 30.0$) or obese ($BMI \geq 30.0$) [17], and rates of obesity worsen with increasing age, with more than 75% of workers over the age of 60 years old being overweight or obese [17]. The obesity epidemic is also a growing problem in the U.S. workforce, with an increase of 44% in the prevalence rate of obesity among US workers was found when comparing the data of the National Health and Nutrition Examination Surveys in the last two decades [17].

The overall goal of this project was to develop BSP models based on a set of full time workers across wide age and BMI ranges. In this report, we will focus on calculating three BSPs, including segment mass, center of mass, and radius of gyration for major body segments such as the torso, thigh, shank, upper arm, and forearm

## B. Aim 1

### "Quantify the Impact of Obesity and Aging on Normalized Body Segment Parameters"

The following three specific objectives, related to Aim 1, were achieved:

- Objective 1: Investigate the impact of BMI on segment parameters, using models including BMI and BMI2 as predictors for BSPs in order to account for nonlinearity.
- Objective 2: Determine the significance of the impact of age predictors including age and age2 being added to the initial model using only BMI predictors.
- Objective 3: Determine the significance of the impact of the interaction terms between age and BMI predictors.

### 1. Methods

A total of 280 working adults (148 female) ages 21-70 (mean: 44.9 ± 13.4 years) participated in this study. Participants were recruited according to gender, age, and BMI, in order to attempt to enroll equal numbers in four BMI categories (normal weight: 18.5 ≤ BMI < 25.0, overweight: 25.0 ≤ BMI < 30.0, obese: 30.0 ≤ BMI < 40.0, and morbidly obese BMI ≥ 40.0 kg m-2) across three age groups (21 ≤ age < 40), middle (40 ≤ age < 55), and old (55 ≤ age < 70).

After obtaining informed written consent, each participant had his or her height and mass recorded in order to confirm eligibility based on BMI. Female participants of child bearing age were then required to complete a pregnancy test, with a negative result being required for eligibility. A whole body DXA scan (Hologic QDR 1000/W, Bedford, MA, USA) of each participant was then collected using the same methods used in prior studies [16,18], with the participant lying supine as shown in Figure 1.

The analysis consisted of each scan being split into each major body segment of interest (torso, upper arm, forearm, thigh, and shank), defined using bony landmarks and anatomically defined planes [14], as shown in Figure 2. Each segment was then split into 3.9 cm tall slices, perpendicular to the long axes of the bones for the arms and legs, and horizontal for the torso, in a similar method as described by Ganley and Powers (19). Pixel densities had assumed values of 2.5-3.0 g cm-3 for bone, 0.9 g cm-3 for fat, and 1.08 g $cm^{-3}$ for lean tissue. The segment mass, center of mass (COM) and radius of gyration (RG) were then calculated from the known slice heights and masses using a custom MATLAB script (Mathworks, Natick, MA, USA). The scan analyses were all performed by trained researchers who had proven to be reliable to within 2% of each other for calculated parameters.

Figure 1: Example of a whole body DXA scan.

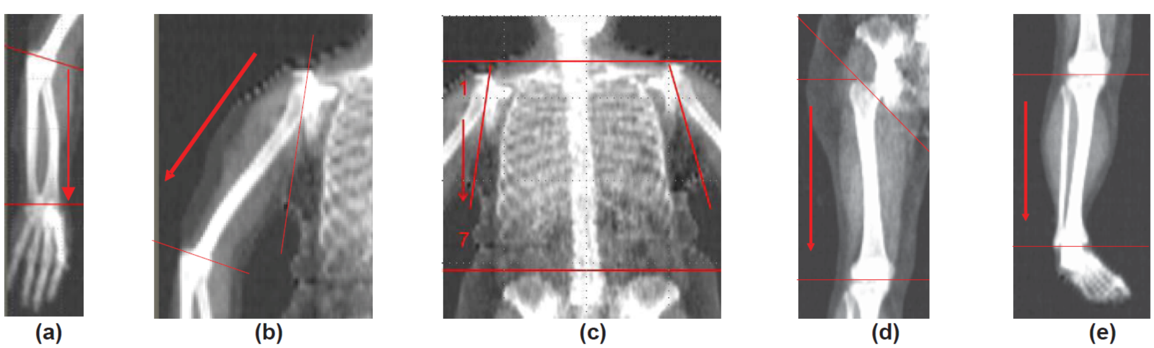


Figure 2: Segmental boundaries of interest: (a) forearm, (b) upper arm, (c) torso, (d) thigh, (e) shank

All reported data for the forearm, upper arm, thigh, and shank were analyzed on the participants' self-reported dominant side. Values for segment mass were reported as percent of the total body mass. COM locations were reported as percent of the segment length, where a higher value indicates that the COM is located further in the distal (inferior for the torso) direction. The RG values were also reported as percent of the segment length, with the RG location being measured from the calculated COM.

The statistical analysis was divided into multiple steps in order to closely examine the impacts of age, gender, and BMI on segment parameters, and to present the resulting models in a useful manner. All parameters were checked for normality, and log transformed as necessary before any further analysis. For all analyses, statistical significance was set at $\alpha = 0.05$. All analyses were performed in JMP Pro 12 (SAS Institute, Cary, NC, USA).

Preliminary analyses. All data were reported stratified by gender and age. All subjects were then analyzed with a model including BMI, age, and gender as predictors. Due to the significance of gender interactions in several of the models, the subjects were then split by gender, and analyzed separately for the remainder of the analysis. Next, a linear regression model was fitted to both gender categories using age, BMI, and the age x BMI interaction term in order to quantify the general effect sizes and significance of the two predictors.

Main analyses. The analysis for Objective 1 used a linear regression model for all segment parameters using BMI and $BMI^2$ as predictors, with all subject separated by gender. For Objective 2, age and $age^2$ were added as predictors to the model already using BMI and $BMI^2$. The significance of adding the age predictors was determined using a nested F-test. For Objective 3, the interaction terms between age and BMI (age x BMI, $age^2$ x BMI, age x $BMI^2$, and $age^2$ x $BMI^2$) were added to the second model, using only age and BMI predictors. The significance of the collective age x BMI interaction terms was determined using a nested F-test.

Following the analyses for the three objectives, the subjects were then split into the three age groups for which they were recruited. An analysis similar to Objective 1 was then performed on each of the gender and age separated groups, using BMI and $BMI^2$ as segment parameter predictors, in order to specifically quantify how BMI affects the parameters at different age stratifications

## 2. Results

Preliminary Analysis. All data were compiled and initially reported stratified by gender and age groups (Table 1). Each parameter was checked for normality using a Shapiro-Wilk test, and log transformed if the distribution was determined to be not normal. All subsequent analysis used the transformed data where necessary.

In order to determine the general impact of age, gender, and BMI, a regression analysis was performed on all participants using these three predictors, as well as all first order interactions. Due to the statistical significance of several interaction terms involving gender (Table 2), all further analysis was performed with the participants separated by gender.

Next, a linear regression was performed on the gender stratified data, using age, BMI, and the age x BMI interaction as predictors for each segment parameter in order to investigate the general effects of age and BMI on the measures, as well as how they interact as predictors. Again, there were several significant effects of age, BMI, and their interaction on the measured parameters (Table 3).

Table 1: Descriptive statistics for all participants, stratified by gender and age group. Values are given as mean ± standard deviation.

| | All Subjects | All Female | All Male | Female | | | Male | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Young | Middle | Old | Young | Middle | Old |
| N | 280 | 148 | 132 | 51 | 44 | 53 | 45 | 49 | 38 |
| Thigh COM (%SL) | 46.2± 1.8 | 45.8± 1.6 | 46.5± 1.9 | 45.7± 1.5 | 45.4± 1.7 | 46.2± 1.6 | 46.2± 1.2 | 46.6± 2.5 | 46.9± 1.5 |
| Thigh Mass (%BW) | 11.5± 1.4 | 11.8± 1.5 | 11.1± 1.3 | 12.3± 1.4 | 11.6± 1.5 | 11.6± 1.4 | 11.7± 0.8 | 11.1± 1.5 | 10.3± 0.8 |
| Thigh Rg (%SL) | 25.5± 0.5 | 25.7± 0.5 | 25.3± 0.4 | 25.6± 0.4 | 25.7± 0.5 | 25.8± 0.6 | 25.2± 0.4 | 25.2± 0.4 | 25.5± 0.4 |
| Torso COM (%SL) | 53.7± 1.4 | 54.4± 1.3 | 53.0± 1.3 | 53.9± 1.0 | 54.3± 1.1 | 54.9± 1.4 | 52.4± 1.1 | 53.1± 1.3 | 53.7± 1.2 |
| Torso Mass (%BW) | 43.5± 3.3 | 43.5± 3.5 | 43.6± 3.2 | 42.2± 2.7 | 44.0± 3.6 | 44.4± 3.8 | 42.4± 2.9 | 43.5± 3.3 | 45.0± 2.8 |
| Torso Rg (%SL) | 27.3± 0.7 | 27.3± 0.7 | 27.3± 0.7 | 27.5± 0.7 | 27.3± 0.6 | 27.2± 0.6 | 27.5± 0.7 | 27.2± 0.6 | 27.0± 0.6 |
| Upper Arm COM (%SL) | 49.4± 2.3 | 49.6± 2.3 | 49.2± 2.3 | 49.8± 1.9 | 50.0± 2.5 | 49.2± 2.6 | 49.4± 2.3 | 48.8± 2.3 | 49.4± 2.4 |
| Upper Arm Mass (%BW) | 3.6± 0.4 | 3.5± 0.4 | 3.8± 0.4 | 3.4± 0.4 | 3.5± 0.5 | 3.6± 0.4 | 3.9± 0.5 | 3.9± 0.3 | 3.7± 0.4 |
| Upper Arm Rg (%SL) | 25.3± 0.9 | 25.4± 0.9 | 25.3± 0.9 | 25.4± 0.9 | 25.3± 1.0 | 25.4± 0.8 | 25.2± 0.9 | 25.3± 1.0 | 25.3± 0.8 |
| Forearm COM (%SL) | 41.4± 1.2 | 41.3± 1.4 | 41.5± 0.9 | 41.4± 1.0 | 41.0± 1.3 | 41.5± 1.7 | 41.5± 0.8 | 41.3± 0.8 | 41.8± 1.1 |
| Forearm Mass (%BW) | 1.5± 0.3 | 1.4± 0.2 | 1.6± 0.3 | 1.4± 0.2 | 1.4± 0.2 | 1.3± 0.2 | 1.7± 0.2 | 1.6± 0.4 | 1.6± 0.2 |
| Forearm Rg (%SL) | 26.6± 0.4 | 26.7± 0.5 | 26.5± 0.3 | 26.6± 0.5 | 26.6± 0.4 | 26.7± 0.6 | 26.5± 0.3 | 26.5± 0.2 | 26.6± 0.3 |
| Shank COM (%SL) | 40.4± 1.2 | 40.1± 1.3 | 40.7± 0.9 | 40.4± 1.1 | 40.0± 1.2 | 39.9± 1.6 | 40.7± 0.9 | 40.5± 1.0 | 41.0± 0.9 |
| Shank Mass (%BW) | 4.1± 0.5 | 4.2± 0.6 | 4.1± 0.5 | 4.4± 0.5 | 4.1± 0.7 | 4.1± 0.5 | 4.2± 0.5 | 4.0± 0.5 | 4.0± 0.4 |
| Shank Rg (%SL) | 26.3± 0.6 | 26.1± 0.6 | 26.4± 0.6 | 26.1± 0.5 | 26.2± 0.5 | 26.2± 0.6 | 26.4± 0.6 | 26.4± 0.5 | 26.4± 0.6 |

Table 2: P and $R^2$ values for the analysis using age, BMI, and gender as segment parameter predictors. NS: non-significant, p > 0.05.

| | Thigh COM | Thigh M | Thigh Rg | Torso COM | Torso M | Torso Rg | Upper Arm COM | Upper Arm M | Upper Arm Rg | Forearm COM | Forearm M | Forearm Rg | Shank COM | Shank M | Shank Rg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $P_{Age}$ | 0.035 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | NS | NS | NS | NS | NS | NS | NS | <0.001 | NS |
| $P_{BMI}$ | NS | NS | 0.039 | <0.001 | <0.001 | <0.001 | NS | <0.001 | 0.002 | 0.006 | <0.001 | 0.003 | <0.001 | <0.001 | <0.001 |
| $P_{Gender}$ | <0.001 | <0.001 | <0.001 | <0.001 | NS | 0.001 | NS | <0.001 | NS | NS | <0.001 | 0.004 | <0.001 | <0.001 | <0.001 |
| $P_{Age\ x\ BMI}$ | 0.408 | NS | NS | 0.037 | NS | NS | NS | NS | NS | 0.018 | NS | NS | NS | NS | NS |
| $P_{Age\ x\ Gender}$ | NS | NS | NS | NS | NS | NS | NS | 0.003 | NS | NS | NS | NS | 0.021 | NS | NS |
| $P_{BMI\ x\ Gender}$ | <0.001 | NS | 0.019 | <0.001 | <0.001 | NS | NS | NS | NS | 0.005 | <0.001 | NS | NS | 0.007 | NS |
| $R^2$ | 0.102 | 0.180 | 0.241 | 0.468 | 0.226 | 0.526 | 0.027 | 0.254 | 0.054 | 0.110 | 0.382 | 0.084 | 0.223 | 0.291 | 0.135 |

Table 3: Parameter values and P values for age, BMI, and age x BMI interaction stratified by gender. NS: non-significant, p > 0.05.

| **Female** | Thigh COM | Thigh M | Thigh Rg | Torso COM | Torso M | Torso Rg | Upper Arm COM | Upper Arm M | Upper Arm Rg | Forearm COM | Forearm M | Forearm Rg | Shank COM | Shank M | Shank Rg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean ± SD | 45.8 ± 1.6 | 11.8 ± 1.5 | 25.7 ± 0.5 | 54.4 ± 0.3 | 43.5 ± 3.5 | 27.3 ± 0.7 | 49.6 ± 2.3 | 3.5 ± 0.4 | 25.4 ± 0.9 | 41.3 ± 1.4 | 1.4 ± 0.2 | 26.7 ± 0.5 | 40.1 ± 1.3 | 4.2 ± 0.6 | 26.1 ± 0.6 |
| $P_{Age}$ | NS | 0.005 | NS | <0.001 | 0.002 | <0.001 | NS | 0.006 | NS | NS | NS | NS | 0.029 | 0.014 | NS |
| $P_{BMI}$ | 0.019 | 0.027 | NS | 0.013 | NS | <0.001 | NS | <0.001 | 0.001 | <0.001 | <0.001 | 0.003 | <0.001 | <0.001 | 0.003 |
| $P_{Age\ x\ BMI}$ | NS | NS | NS | NS | NS | 0.044 | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| | | | | | | | | | | | | | | | |
| **Male** | Thigh COM | Thigh M | Thigh Rg | Torso COM | Torso M | Torso Rg | Upper Arm COM | Upper Arm M | Upper Arm Rg | Forearm COM | Forearm M | Forearm Rg | Shank COM | Shank M | Shank Rg |
| Mean ± SD | 46.5 ± 1.9 | 11.1 ± 1.3 | 25.3 ± 0.4 | 53.0 ± 1.3 | 43.6 ± 3.2 | 27.3 ± 0.7 | 49.2 ± 2.3 | 3.8 ± 0.4 | 25.3 ± 0.9 | 41.5 ± 0.9 | 1.6 ± 0.3 | 26.5 ± 0.3 | 40.7 ± 0.9 | 4.1 ± 0.5 | 26.4 ± 0.6 |
| $P_{Age}$ | NS | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | NS | 0.047 | NS | NS | NS | NS | NS | 0.008 | NS |
| $P_{BMI}$ | 0.003 | NS | 0.002 | <0.001 | <0.001 | <0.001 | NS | NS | NS | NS | <0.001 | NS | <0.001 | <0.001 | <0.001 |
| $P_{Age\ x\ BMI}$ | NS | NS | NS | 0.016 | NS | NS | 0.012 | 0.038 | NS | 0.007 | NS | NS | 0.043 | NS | NS |

Objective 1 results. The analysis for Objective 1 showed several significant effects of both BMI and $BMI^2$ on the gender stratified segment parameters (Table 4), particularly in the radius of gyration locations in both genders.

Objective 2 results. Objective 2 analysis, which employed a regression model using BMI, $BMI^2$, age, and $age^2$ as the predictors, showed that the age terms had significant effects on the parameters of interest (Table 5). Additionally, the nested F-test indicated that where the age or $age^2$ terms did not have a significant impact individually, when added together to the initial model from Objective 1, they have a significant effect, as indicated by the P1 values.

Objective 3 results. Objective 3 examined the impact of adding the age x BMI interaction terms to the model used for Objective 2, which did not provide any insight into how age and BMI interact in predicting segment parameters. Again, the interaction terms had significant effects on segment parameter prediction both individually, and as a whole, as represented by the P2 values, determined by another nested F-test (Table 5).

After stratifying each gender by age group, and performing the same analysis as in Objective 1, several significant effects of BMI appeared (Table 6), indicating that within age groups, BMI still has an effect on segment parameters.

Table 4: P, $R^2$, and β values for BMI and BMI$^2$ for each segment parameter, separated by gender. β values are provided as mean ± standard error.

| FEMALE | Thigh M | | | Thigh COM | | | Thigh Rg | | |
|---|---|---|---|---|---|---|---|---|---|
| | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE |
| BMI | 0.118 | | 0.168 ± 0.107 | 0.107 | | -0.189 ± 0.117 | 0.086 | | -0.060 ± 0.035 |
| BMI$^2$ | 0.187 | 0.039 | -0.002 ± 0.002 | 0.052 | 0.065 | 0.003 ± 0.002 | 0.076 | 0.022 | 0.001 ± 0.0005 |
| | Torso M | | | Torso COM | | | Torso Rg | | |
| | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE |
| BMI | 0.126 | | 0.391 ± 0.254 | 0.041 | | -0.186 ± 0.090 | <0.001 | | -0.194 ± 0.036 |
| BMI$^2$ | 0.188 | 0.032 | -0.005 ± 0.004 | 0.016 | 0.084 | 0.003 ± 0.001 | <0.001 | 0.492 | 0.002 ± 0.001 |
| | Upper Arm M | | | Upper Arm COM | | | Upper Arm Rg | | |
| | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE |
| BMI | 0.275 | | 0.032 ± 0.029 | 0.292 | | 0.168 ± 0.173 | 0.001 | | -0.174 ± 0.062 |
| BMI$^2$ | 0.649 | 0.146 | -0.0001 ± 0.0004 | 0.333 | 0.01 | -0.003 ± 0.002 | 0.006 | 0.132 | 0.003 ± 0.001 |
| | Forearm M | | | Forearm COM | | | Forearm Rg | | |
| | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE |
| BMI | 0.309 | | -0.012 ± 0.012 | 0.002 | | 0.236 ± 0.093 | 0.741 | | -0.012 ± 0.037 |
| BMI$^2$ | 0.838 | 0.216 | 0.00004 ± 0.0002 | 0.012 | 0.161 | -0.004 ± 0.001 | 0.962 | 0.056 | -0.00003 ± 0.001 |
| | Shank M | | | Shank COM | | | Shank Rg | | |
| | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE |
| BMI | 0.066 | | -0.074 ± 0.040 | <0.001 | | -0.295 ± 0.087 | 0.002 | | -0.124 ± 0.039 |
| BMI$^2$ | 0.197 | 0.126 | 0.001 ± 0.001 | 0.008 | 0.208 | 0.003 ± 0.001 | 0.005 | 0.105 | 0.002 ± 0.001 |

| MALE | Thigh M | | | Thigh COM | | | Thigh Rg | | |
|---|---|---|---|---|---|---|---|---|---|
| | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE |
| BMI | 0.049 | | 0.243 ± 0.131 | 0.076 | | -0.344 ± 0.192 | 0.076 | | -0.077 ± 0.043 |
| BMI$^2$ | 0.065 | 0.037 | -0.004 ± 0.002 | 0.142 | 0.071 | 0.004 ± 0.003 | 0.127 | 0.055 | 0.001 ± 0.001 |
| | Torso M | | | Torso COM | | | Torso Rg | | |
| | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE |
| BMI | 0.455 | | 0.206 ± 0.276 | 0.133 | | -0.663 ± 0.110 | <0.001 | | -0.204 ± 0.050 |
| BMI$^2$ | 0.875 | 0.322 | 0.001 ± 0.004 | 0.546 | 0.325 | 0.002 ± 0.002 | 0.006 | 0.506 | 0.002 ± 0.001 |
| | Upper Arm M | | | Upper Arm COM | | | Upper Arm Rg | | |
| | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE |
| BMI | 0.015 | | 0.101 ± 0.041 | 0.056 | | -0.462 ± 0.239 | 0.519 | | -0.044 ± 0.093 |
| BMI$^2$ | 0.02 | 0.051 | -0.001 ± 0.001 | 0.084 | 0.045 | 0.006 ± 0.004 | 0.635 | 0.019 | 0.001 ± 0.001 |
| | Forearm M | | | Forearm COM | | | Forearm Rg | | |
| | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE |
| BMI | 0.152 | | -0.041 ± 0.029 | 0.754 | | -0.025 ± 0.097 | <0.001 | | -0.123 ± 0.030 |
| BMI$^2$ | 0.532 | 0.282 | 0.0003 ± 0.0004 | 0.796 | 0.002 | 0.0005 ± 0.001 | <0.001 | 0.122 | 0.002 ± 0.0005 |
| | Shank M | | | Shank COM | | | Shank Rg | | |
| | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE | P | $R^2$ | β ± SE |
| BMI | 0.236 | | -0.043 ± 0.036 | 0.017 | | -0.222 ± 0.092 | <0.001 | | -0.241 ± 0.053 |
| BMI$^2$ | 0.994 | 0.454 | -3.8E-6 ± 0.001 | 0.049 | 0.126 | 0.003 ± 0.001 | <0.001 | 0.202 | 0.003 ± 0.001 |

Table 5: P values for BMI, age, and BMI x age interaction terms, as well as nested P values for adding age and interaction terms. P1 represents the significance of adding age and $age^2$ terms to the initial model only using BMI terms, and P2 represents the significance of adding the BMI x age interaction terms to the model only using BMI and age terms.

| **FEMALE** | Thigh M | Thigh COM | Thigh Rg | Torso M | Torso COM | Torso Rg | Upper Arm M | Upper Arm COM | Upper Arm Rg | Forearm M | Forearm COM | Forearm Rg | Shank M | Shank COM | Shank Rg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BMI | 0.028 | 0.066 | 0.105 | 0.157 | 0.006 | <0.001 | 0.202 | 0.359 | 0.007 | 0.355 | 0.025 | 0.438 | 0.078 | <0.001 | 0.005 |
| $BMI^2$ | 0.053 | 0.027 | 0.097 | 0.230 | 0.002 | <0.001 | 0.489 | 0.293 | 0.002 | 0.907 | 0.009 | 0.626 | 0.218 | 0.001 | 0.015 |
| Age | 0.030 | 0.082 | 0.675 | 0.072 | 0.225 | 0.984 | 0.967 | 0.263 | 0.798 | 0.614 | 0.216 | 0.395 | 0.537 | 0.301 | 0.587 |
| $Age^2$ | 0.070 | 0.053 | 0.831 | 0.152 | 0.068 | 0.622 | 0.773 | 0.229 | 0.724 | 0.458 | 0.210 | 0.297 | 0.737 | 0.199 | 0.490 |
| Age x BMI | 0.191 | 0.429 | 0.581 | 0.788 | 0.034 | 0.334 | 0.799 | 0.886 | 0.074 | 0.266 | 0.388 | 0.707 | 0.201 | 0.046 | 0.778 |
| $Age^2$ x BMI | 0.139 | 0.327 | 0.576 | 0.961 | 0.017 | 0.465 | 0.792 | 0.986 | 0.095 | 0.188 | 0.659 | 0.541 | 0.213 | 0.029 | 0.726 |
| Age x $BMI^2$ | 0.149 | 0.539 | 0.646 | 0.881 | 0.040 | 0.337 | 0.766 | 0.960 | 0.100 | 0.217 | 0.379 | 0.809 | 0.196 | 0.032 | 0.812 |
| $Age^2$ x $BMI^2$ | 0.103 | 0.420 | 0.641 | 0.957 | 0.020 | 0.454 | 0.775 | 0.912 | 0.129 | 0.153 | 0.065 | 0.626 | 0.206 | 0.019 | 0.755 |
| P1 (Age only) | <0.001 | 0.036 | 0.185 | <0.001 | <0.001 | <0.001 | 0.009 | 0.423 | 0.905 | 0.167 | 0.645 | 0.171 | 0.015 | 0.014 | 0.382 |
| P2 (Age x BMI) | 0.106 | 0.446 | 0.942 | 0.212 | 0.038 | 0.245 | 0.726 | 0.505 | 0.089 | 0.121 | 0.007 | 0.309 | 0.786 | 0.020 | 0.970 |

| **MALE** | Thigh M | Thigh COM | Thigh Rg | Torso M | Torso COM | Torso Rg | Upper Arm M | Upper Arm COM | Upper Arm Rg | Forearm M | Forearm COM | Forearm Rg | Shank M | Shank COM | Shank Rg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BMI | 0.005 | 0.054 | 0.008 | 0.919 | 0.180 | <0.001 | 0.004 | 0.056 | 0.645 | 0.369 | 0.221 | <0.001 | 0.554 | 0.006 | <0.001 |
| $BMI^2$ | 0.005 | 0.113 | 0.017 | 0.489 | 0.032 | 0.017 | 0.007 | 0.082 | 0.536 | 0.841 | 0.198 | <0.001 | 0.620 | 0.020 | <0.001 |
| Age | 0.665 | 0.714 | 0.005 | 0.172 | 0.260 | 0.580 | 0.535 | 0.096 | 0.986 | 0.087 | 0.018 | 0.002 | 0.250 | 0.067 | 0.251 |
| $Age^2$ | 0.707 | 0.533 | <0.001 | 0.509 | 0.823 | 0.967 | 0.276 | 0.085 | 0.911 | 0.122 | 0.007 | 0.002 | 0.451 | 0.037 | 0.194 |
| Age x BMI | 0.417 | 0.515 | 0.016 | 0.073 | 0.945 | 0.958 | 0.221 | 0.718 | 0.721 | 0.037 | 0.080 | 0.007 | 0.730 | 0.322 | 0.799 |
| $Age^2$ x BMI | 0.319 | 0.598 | 0.022 | 0.069 | 0.863 | 0.900 | 0.202 | 0.655 | 0.625 | 0.023 | 0.062 | 0.012 | 0.641 | 0.236 | 0.615 |
| Age x $BMI^2$ | 0.570 | 0.441 | 0.013 | 0.114 | 0.885 | 0.892 | 0.389 | 0.751 | 0.662 | 0.071 | 0.086 | 0.006 | 0.812 | 0.372 | 0.883 |
| $Age^2$ x $BMI^2$ | 0.440 | 0.521 | 0.018 | 0.099 | 1.000 | 0.839 | 0.340 | 0.666 | 0.556 | 0.043 | 0.074 | 0.010 | 0.728 | 0.266 | 0.696 |
| P1 (Age only) | <0.001 | 0.176 | <0.001 | <0.001 | <0.001 | <0.001 | 0.001 | 0.013 | 0.959 | 0.530 | 0.002 | <0.001 | <0.001 | 0.003 | 0.034 |
| P2 (Age x BMI) | 0.229 | 0.748 | 0.119 | 0.063 | 0.125 | 0.913 | 0.031 | 0.414 | 0.277 | 0.025 | 0.002 | 0.035 | 0.704 | 0.287 | 0.447 |

Table 6: Effect of BMI and BMI$^2$ on segment parameters stratified by gender and age group.

| **Young Female** | Thigh M | Thigh COM | Thigh Rg | Torso M | Torso COM | Torso Rg | Upper Arm M | Upper Arm COM | Upper Arm Rg | Forearm M | Forearm COM | Forearm Rg | Shank M | Shank COM | Shank Rg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $P_{BMI}$ | 0.020 | 0.066 | 0.349 | 0.400 | 0.003 | <0.001 | 0.447 | 0.091 | 0.003 | 0.769 | 0.281 | 0.099 | 0.741 | <0.001 | 0.166 |
| $P_{BMI^2}$ | 0.023 | 0.034 | 0.276 | 0.322 | 0.002 | <0.001 | 0.612 | 0.084 | 0.001 | 0.482 | 0.395 | 0.138 | 0.919 | <0.001 | 0.309 |
| $R^2$ | 0.109 | 0.168 | 0.051 | 0.045 | 0.216 | 0.683 | 0.086 | 0.062 | 0.247 | 0.187 | 0.083 | 0.084 | 0.199 | 0.417 | 0.179 |

| **Middle Female** | Thigh M | Thigh COM | Thigh Rg | Torso M | Torso COM | Torso Rg | Upper Arm M | Upper Arm COM | Upper Arm Rg | Forearm M | Forearm COM | Forearm Rg | Shank M | Shank COM | Shank Rg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $P_{BMI}$ | 0.143 | 0.043 | 0.156 | 0.497 | 0.041 | 0.006 | 0.982 | 0.311 | 0.189 | 0.815 | 0.742 | 0.343 | 0.133 | 0.006 | 0.0215 |
| $P_{BMI^2}$ | 0.199 | 0.038 | 0.182 | 0.562 | 0.026 | 0.034 | 0.672 | 0.319 | 0.104 | 0.569 | 0.5814 | 0.418 | 0.172 | 0.012 | 0.253 |
| $R^2$ | 0.096 | 0.103 | 0.055 | 0.026 | 0.156 | 0.506 | 0.212 | 0.025 | 0.187 | 0.161 | 0.08 | 0.05 | 0.08 | 0.234 | 0.05 |

| **Old Female** | Thigh M | Thigh COM | Thigh Rg | Torso M | Torso COM | Torso Rg | Upper Arm M | Upper Arm COM | Upper Arm Rg | Forearm M | Forearm COM | Forearm Rg | Shank M | Shank COM | Shank Rg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $P_{BMI}$ | 0.741 | 0.576 | 0.321 | 0.043 | 0.977 | 0.204 | 0.03 | 0.54 | 0.355 | 0.031 | <0.001 | 0.346 | 0.292 | 0.67 | 0.012 |
| $P_{BMI^2}$ | 0.591 | 0.744 | 0.309 | 0.057 | 0.935 | 0.550 | 0.054 | 0.617 | 0.278 | 0.12 | <0.002 | 0.207 | 0.539 | 0.993 | 0.018 |
| $R^2$ | 0.050 | 0.062 | 0.021 | 0.090 | 0.060 | 0.354 | 0.182 | 0.021 | 0.049 | 0.345 | 0.423 | 0.127 | 0.192 | 0.166 | 0.133 |

| **Young Male** | Thigh M | Thigh COM | Thigh Rg | Torso M | Torso COM | Torso Rg | Upper Arm M | Upper Arm COM | Upper Arm Rg | Forearm M | Forearm COM | Forearm Rg | Shank M | Shank COM | Shank Rg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $P_{BMI}$ | 0.107 | 0.111 | 0.001 | 0.660 | 0.956 | 0.015 | 0.019 | 0.239 | 0.281 | 0.49 | 0.33 | <0.001 | 0.22 | 0.104 | <0.001 |
| $P_{BMI^2}$ | 0.107 | 0.277 | 0.001 | 0.434 | 0.668 | 0.075 | 0.037 | 0.401 | 0.211 | 0.456 | 0.211 | <0.001 | 0.757 | 0.263 | <0.001 |
| $R^2$ | 0.061 | 0.316 | 0.297 | 0.160 | 0.177 | 0.462 | 0.194 | 0.169 | 0.074 | 0.285 | 0.131 | 0.35 | 0.568 | 0.314 | 0.38 |

| **Middle Male** | Thigh M | Thigh COM | Thigh Rg | Torso M | Torso COM | Torso Rg | Upper Arm M | Upper Arm COM | Upper Arm Rg | Forearm M | Forearm COM | Forearm Rg | Shank M | Shank COM | Shank Rg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $P_{BMI}$ | 0.243 | 0.213 | 0.935 | 0.070 | 0.096 | 0.015 | 0.367 | 0.51 | 0.627 | 0.052 | 0.153 | 0.335 | 0.466 | 0.521 | 0.001 |
| $P_{BMI^2}$ | 0.213 | 0.247 | 0.956 | 0.247 | 0.020 | 0.118 | 0.322 | 0.559 | 0.53 | 0.126 | 0.202 | 0.387 | 0.978 | 0.67 | 0.003 |
| $R^2$ | 0.043 | 0.046 | 0.034 | 0.482 | 0.510 | 0.640 | 0.036 | 0.02 | 0.046 | 0.303 | 0.087 | 0.039 | 0.487 | 0.088 | 0.337 |

| **Old Male** | Thigh M | Thigh COM | Thigh Rg | Torso M | Torso COM | Torso Rg | Upper Arm M | Upper Arm COM | Upper Arm Rg | Forearm M | Forearm COM | Forearm Rg | Shank M | Shank COM | Shank Rg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $P_{BMI}$ | 0.003 | 0.240 | 0.193 | 0.184 | 0.566 | 0.134 | 0.089 | 0.079 | 0.374 | 0.015 | 0.023 | 0.076 | 0.799 | 0.004 | 0.767 |
| $P_{BMI^2}$ | 0.003 | 0.330 | 0.255 | 0.065 | 0.292 | 0.347 | 0.1 | 0.069 | 0.34 | 0.002 | 0.046 | 0.088 | 0.5 | 0.006 | 0.813 |
| $R^2$ | 0.232 | 0.120 | 0.101 | 0.443 | 0.376 | 0.460 | 0.085 | 0.099 | 0.034 | 0.616 | 0.267 | 0.095 | 0.307 | 0.22 | 0.011 |

## 3. Discussion

Overall, the results indicate that there are several significant effects of gender, age, BMI, and the interaction between age and BMI on several important body segment parameters in the working adult population.

Preliminary analysis. The initial analysis for males and females showed that age and BMI have several significant effects on the parameters of interest, and the interaction of gender with these terms indicates that it is appropriate to treat the genders separately when attempting to calculate segment parameters. While the regressions using age, BMI, and gender offer improvements over some of the current methods that only differentiate by gender [14], more precise effects can be discovered by analyzing the genders and age groups separately.

Objective 1. Investigating the effect of BMI (in its linear and quadratic terms) on the parameters of interest provides more insight into how men and women changes in terms of body mass distribution with increasing BMI. For example, some parameters, such as the upper arm center of mass, show the effects of increasing BMI moving in opposite directions based on gender (Table 4). In this example, increasing BMI in females correlates with a more distal COM, while increasing BMI in males correlates with a more proximal COM.

For other segments, such as the torso, both men and women appear to increase the fraction of total body mass in the torso with increasing BMI, women appear to have a larger effect size with increased BMI. Looking more at the torso segment, the significant decrease in radius of gyration in men and women indicates that as the torso mass increases, it appears to do so concentrated in the area of the torso closer to the center of mass, as opposed to gaining mass throughout the torso. The results of the investigation related to Objective 1 appear to validate the need to observe the impacts of BMI on segment parameters in men and women separately.

Objective 2. Next, the addition of the age terms (again, in its linear and quadratic contributions) provides more accuracy into predicting segment parameters. For this analysis, it is important to consider the significance of the nested F-test, which accounts for adding both of the age terms together, as opposed to adding and evaluating the linear age term by itself. While the individual terms only appear significant for a few parameters, such as the thigh mass in females, and the thigh radius of gyration and forearm parameters in males, the nested F-test performed indicates that adding age and $age^2$ terms to the model already containing BMI terms will significantly improve the model (Table 5).

Objective 3. In order to determine the interaction between age and obesity status, due to the population-wide increase in obesity with age [17], the set of age x BMI interaction terms were then added to the model including age and BMI terms without the interactions. Similarly to the Objective 2 analysis, there were a few examples of individual interaction terms having an effect on segment parameters (such as torso center of mass in women, and forearm parameters in men), but several significant effects of the interactions as a whole being added to the model, as indicated by the second nested F-test (Table 5). Because these results indicate that the impact of BMI appears to be changing with increasing age, further investigation is warranted into how BMI affects segment parameters at different age levels.

The final analysis performed, with the participants stratified by gender and age, indicates that BMI has some significant effects on segment parameters, regardless of age (Table 6). More importantly, this analysis demonstrates that BMI changes have different effects at different ages. For example, BMI has a significant effect on thigh radius of gyration only in younger men, and not men in the middle or older age group. Some of these differences are likely due to the increase muscle mass in younger men, and how additional body mass is added and distributed with increasing BMI. Because obesity tends to worsen with age, the most appropriate analysis may be to separate the population by age group in order to isolate differing effects of obesity at different ages.

## C. Aim 2

### *"Develop regression models to predict BSPs that include BMI"*

#### 1. Methods

The same methods as in Aim 1 were used except for the statistical analyses, which are described here. A backwards stepwise regression analysis was performed on the thigh and torso segment parameters for 200 (training) out of the full 280 participants included in the study. The other 80 subjects will be used as a validation sample. The initial models contained age, BMI, and all relevant physical measures taken of the body segment of interest. For each model, genders were analyzed separately, with age and BMI locked in as predictors. In each step of the analysis, the predictor with the largest P-value was removed, and the analysis was repeated. This process of removing the least significant predictor and repeating the analysis continued until the P-values for all predictors were below 0.10. All analyses were performed in JMP Pro 12 (SAS Institute, Cary, NC, USA).

#### 2. Results

Several significant effects were found from the anthropometric measurements on the thigh and trunk segments in men and women (Table 7). For all six of the segment parameters of interest, waist circumference, hip circumference, or waist-hip ratio (WHR) were included in the final models. The new models appear to show the highest increase in accuracy (compared to the final Aim 1 models using age and BMI as predictors) in torso and thigh mass in women. All three thigh parameters in men also had $\Delta R^2$ values of over 0.2 compared to the previous models not including body measurements

Table 7: P values for predictors remaining after backwards stepwise regression. $R^2$ values are for the final models, and $\Delta R^2$ values are for the improvement from the final model in Aim 1 (using BMI, age, and all interactions as predictors).

**FEMALE**

| Torso COM | | Torso Mass | | Torso Rg | |
|---|---|---|---|---|---|
| Predictor | P-value | Predictor | P-value | Predictor | P-value |
| Age | <0.001 | Age | 0.950 | Age | 0.586 |
| BMI | 0.714 | BMI | <0.001 | BMI | 0.194 |
| L3L4 trunk width | 0.046 | Shoulder trunk depth | 0.067 | Shoulder trunk depth | 0.004 |
| Inter-ASIS distance | 0.020 | Breast trunk depth | <0.001 | Mid-breast trunk depth | 0.028 |
| Breast trunk depth | 0.001 | L3L4 trunk depth | 0.011 | Breast trunk depth | 0.014 |
| Waist circumference | 0.003 | Waist circumference | 0.008 | Waist circumference | <0.001 |
| WHR | 0.011 | Hip circumference | 0.048 | Hip circumference | <0.001 |
| | | WHR | 0.033 | WHR | <0.001 |
| $R^2$ | 0.448 | $R^2$ | 0.606 | $R^2$ | 0.700 |
| $\Delta R^2$ | 0.169 | $\Delta R^2$ | 0.468 | $\Delta R^2$ | 0.137 |

| Thigh COM | | Thigh Mass | | Thigh Rg | |
|---|---|---|---|---|---|
| Predictor | P-value | Predictor | P-value | Predictor | P-value |
| Age | 0.407 | Age | 0.970 | Age | 0.202 |
| BMI | 0.004 | BMI | <0.001 | BMI | 0.641 |
| Upper thigh circumference | 0.001 | Upper thigh circumference | 0.008 | Mid-thigh circumference | 0.001 |
| Lower thigh circumference | <0.001 | Mid-thigh circumference | 0.001 | Knee circumference | <0.001 |
| Hip circumference | 0.001 | Waist circumference | 0.023 | | |
| | | Hip circumference | 0.035 | | |
| | | WHR | 0.094 | | |
| $R^2$ | 0.307 | $R^2$ | 0.631 | $R^2$ | 0.223 |
| $\Delta R^2$ | 0.185 | $\Delta R^2$ | 0.468 | $\Delta R^2$ | 0.174 |

Table 7 (cont.)

**MALE**

| Torso COM | | Torso Mass | | Torso Rg | |
|---|---|---|---|---|---|
| Predictor | P-value | Predictor | P-value | Predictor | P-value |
| Age | 0.016 | Age | 0.105 | Age | 0.026 |
| BMI | 0.320 | BMI | 0.177 | BMI | 0.053 |
| Shoulder trunk width | 0.002 | Breast trunk width | 0.047 | L3L4 trunk width | 0.026 |
| Mid-breast trunk width | 0.019 | Inter-ASIS distance | 0.028 | Shoulder trunk depth | <0.001 |
| Shoulder trunk depth | 0.027 | Shoulder trunk depth | 0.002 | Breast trunk depth | <0.001 |
| Breast trunk depth | 0.049 | Mid-breast trunk depth | <0.001 | Mid-breast axis depth | 0.098 |
| L3L4 trunk depth | 0.065 | Shoulder axis depth | 0.002 | L3L4 axis depth | 0.008 |
| Waist circumference | 0.014 | Breast axis depth | 0.024 | Waist circumference | 0.003 |
| WHR | 0.027 | Hip circumference | 0.007 | WHR | <0.001 |
| $R^2$ | 0.602 | $R^2$ | 0.652 | $R^2$ | 0.739 |
| $\Delta R^2$ | 0.096 | $\Delta R^2$ | 0.199 | $\Delta R^2$ | 0.166 |

| Thigh COM | | Thigh Mass | | Thigh Rg | |
|---|---|---|---|---|---|
| Predictor | P-value | Predictor | P-value | Predictor | P-value |
| Age | 0.260 | Age | 0.033 | Age | 0.318 |
| BMI | 0.028 | BMI | 0.223 | BMI | 0.284 |
| Upper thigh circumference | 0.002 | Upper thigh circumference | <0.001 | Upper thigh circumference | 0.016 |
| Lower thigh circumference | <0.001 | Waist circumference | 0.012 | Mid-thigh circumference | 0.016 |
| | | | | Knee circumference | <0.001 |
| | | | | Hip circumference | 0.054 |
| $R^2$ | 0.366 | $R^2$ | 0.514 | $R^2$ | 0.541 |
| $\Delta R^2$ | 0.259 | $\Delta R^2$ | 0.271 | $\Delta R^2$ | 0.249 |

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# V. Publications

The following publications are listed in calendar year order by most recent year first.

## A. Peer-Reviewed Journal Papers

Merrill ZF, Bova G, Chambers AJ, Cham R: [2017] Effect of Trunk Segment Boundary Definitions on Frontal Plane Segment Inertial Calculations. Journal of Applied Biomechanics, in press.

Merrill ZF, Perera S, Cham R: [2018] Effect of Age and Body Mass Index on Body Segment Parameters in Working Adults. In preparation.

Merrill ZF, Perera S, Cham R: [2018] Statistical Models for Predicting Body Segment Parameters in Working Adults. In preparation.

## B. Conference Proceedings

Merrill ZF, Chambers AJ, Cham R: [2017] Impact of Age and Body Mass Index on Anthropometry in Working Adults. Proc of 2017 Human Factors and Ergonomics Society 61st International Annual Meeting, Austin, Texas, October 9-13.

Bova G, Merrill ZF, Cham R, Chambers AJ: [2016] Comparison in Segment Mass Values Determined by the Dual Energy X-Ray Absorptiometry Scan Method and the Zatsiorsky Anthropometric Table Calculation Method. Proc of 2016 American Society of Biomechanics 40th Annual Meeting, Raleigh, North Carolina, August 2-5.

Merrill ZF, Cham R: [2016] Effect of Age and Body Mass Index on Torso Anthropometry in Females. Proc of 2016 American Society of Biomechanics 40th Annual Meeting, Raleigh, North Carolina, August 2-5.

Knewtson ME, Merrill ZF, Cham R, Chambers AJ: [2015] Effect of Age on Body Segment Parameters in Normal Weight Females. Proc of 2015 American Society of Biomechanics 39th Annual Meeting, Columbus, Ohio, August 5-8.

Merrill ZF, Chambers AJ, Cham R: [2015] Impact of Mass Redistribution on Lower Extremity Biomechanics During Slipping. Proc of 2015 American Society of Biomechanics 39th Annual Meeting, Columbus, Ohio, August 5-8.

Merrill ZF, Knewtson ME, Cham R, Chambers AJ: [2015] Effect of Increased Body Mass Index on Body Segment Parameters in Males. Proc of 2015 American Society of Biomechanics 39th Annual Meeting, Columbus, Ohio, August 5-8.

# VI. Other

## A. Cumulative Inclusion Enrollment and Gender and Minority Inclusion Table

View Burden Statement

**PHS Inclusion Enrollment Report**

**This report format should NOT be used for collecting data from study participants.**

OMB Number: 0925-0001 and 0925-0002
Expiration Date: 10/31/2018

***Study Title (must be unique):** Obesity and Body Segment Parameters in Working Adults - NIOSH 1 R01 OH010106

* Delayed Onset Study? ☐ Yes ☒ No

***If study is not delayed onset, the following selections are required:***

| | | |
|---|---|---|
| **Enrollment Type** | ☐ Planned | ☒ Cumulative (Actual) |
| **Using an Existing Dataset or Resource** | ☐ Yes | ☐ No |
| **Enrollment Location** | ☒ Domestic | ☐ Foreign |
| **Clinical Trial** | ☐ Yes | ☒ No |
| **NIH-Defined Phase III Clinical Trial** | ☐ Yes | ☒ No |

**Comments:**

| **Racial Categories** | **Ethnic Categories** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Not Hispanic or Latino | | | Hispanic or Latino | | | Unknown/Not Reported Ethnicity | | | **Total** |
| | **Female** | **Male** | **Unknown/ Not Reported** | **Female** | **Male** | **Unknown/ Not Reported** | **Female** | **Male** | **Unknown/ Not Reported** | |
| American Indian/ Alaska Native | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Asian | 3 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| Native Hawaiian or Other Pacific Islander | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Black or African American | 34 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 56 |
| White | 95 | 92 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 189 |
| More than One Race | 14 | 9 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 27 |
| Unknown or Not Reported | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total** | 146 | 128 | 0 | 2 | 4 | 0 | 0 | 0 | 0 | 280 |

## B. Inclusion of Children

Not applicable