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Scaling of Adult Regional Body Mass and Body Composition as a Whole to Height: Relevance to Body Shape and Body Mass Index

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Abstract

Objectives—Adult body mass (MB) empirically scales as height (Ht) squared ($MB \propto Ht^2$), but does regional body mass and body composition as a whole also scale as Ht^2 ? This question is relevant to a wide range of biological topics, including interpretation of body mass index.

Methods—Dual-energy x-ray absorptiometry (DXA) was used to quantify regional body mass (head [MH], trunk, arms, legs) and whole-body composition (fat, lean soft tissue [LST], and bone mineral content [BMC]) in non-Hispanic (NH) white, NH black, Mexican American, and Korean adults participating in the National Health and Nutrition Examination Survey (NHANES; $n=17,126$) and Korean NHANES ($n=8,942$). Regression models were developed to establish Ht scaling powers for each measured component with adjustments for age and adiposity.

Results—Exploratory analyses revealed a consistent scaling pattern across men and women of the four race/ethnic groups: regional mass powers, head ($\sim 0.8-1$) < arms and trunk ($\sim 1.8-2.3$) < legs ($\sim 2.3-2.6$); and body composition, LST ($\sim 2.0-2.3$) < BMC ($\sim 2.1-2.4$). Small sex and race/ethnic differences in scaling powers were also observed. As body mass scaled uniformly across the eight sex and race/ethnic groups as Ht^2 , tall and short subjects differed in body shape (e.g., $M_H/M_B \propto Ht^{-1}$) and composition.

Conclusions—Adult human body shape and relative composition are a function of body size as defined by stature, a finding that has important implications in multiple areas of biological research.

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Keywords

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INTRODUCTION

Tall adult humans weigh more than their short counterparts and this difference in body mass (MB) as it relates to height (Ht) is captured by Quetelet's Rule: $M_B \propto Ht^2$ (Quetelet et al., 1842). The observation that body mass scales to height with a power of 2 is the basis for body mass index (BMI, M_B/Ht^2) now used as a global measure of adiposity and health (Antezana, 2000; Jensen et al., 2013; PiSunyer et al., 1998). While the height power of 2 has long been debated (Benn, 1971; Bogin, 2008; Burton, 2007; Cole, 1991; Diverse Populations Group, 2005; Garn et al., 1986; Green, 2009; Keys et al., 1972; Larsson et al., 2006; Samras, 2007; Smalley et al., 1990; Trefethan, 2013), we recently showed in two large United States (US) and Korean nationally representative samples that body mass scales to height narrowly around a power of 2 across non-Hispanic (NH) white, NH black, Mexican American, and Korean Asian men and women (Heymsfield et al., submitted publication).

The power of 2 observed when body mass is scaled to height across a sample of adults is an empirical observation that at present lacks a theoretical biological or physical basis. Questions have been raised why the power of height is not 3 as would be expected if body mass and height are geometrically related to each other (Burton, 2007; Garn et al., 1986; Samras, 2007; Trefethan, 2013). Several shape indices, including M/H^3 , were applied in adults with this reasoning prior to the widespread adoption of BMI (Cole, 1991; Keys et al., 1972).

Moreover, it is largely unknown if regional body mass and body composition as a whole also scale to height with powers of 2 even though there are reasons to hypothesize the existence of more variable powers. For example, brain mass is only weakly associated with stature and typically scales as $Ht^{0.5-1}$ (Heymsfield et al., 2007, 2009, 2014). Brain mass is thus a smaller fraction of body mass in tall adults compared to their short counterparts (i.e., $\text{brain mass}/M_B \propto Ht^{-1}$). It is thus unlikely that head mass scales similar to body mass (i.e., as Ht^2) unless brain mass is a much smaller fraction of head mass in tall people.

As another example, bone mass in mammals scales to body mass with powers greater than 1 (e.g., $\text{bone mass} \propto M_B^{1.05}$) and large animals thus have a greater fraction of their body mass as skeleton than do small animals (Calder, 1996). Does the same "rule" apply to adult humans and, if so, then it would seem likely that bone mass would scale to height with powers exceeding that observed for body mass. Analysis of regional body mass and body composition scaling to height may thus provide a new opportunity to improve our understanding and interpretation of shape measures such as BMI.

The aim of the present study was to examine regional body mass and whole-body composition scaling to height across NH white, NH black, Mexican American, and Korean Asian men and women. We hypothesized that Quetelet's Rule ($M_B \propto Ht^2$) embraces more

complex and possibly more informative scaling patterns at the regional mass and whole-body composition levels. Our inclusion of race/ethnic groups in these analyses derives from our longer term explorations of BMI as a globally applicable measure of adiposity and health.

METHODS

Study Design and Rationale

The simple allometric model, $Y = \alpha X^\beta \varepsilon$, was applied in the current study in natural logarithmic form as

$$\log_e Y = \log_e \alpha + \beta \log_e X + \log_e \varepsilon \quad (1)$$

with Y dependent variable, X predictor variable, β the scaling exponent, α the proportionality constant, and ε the multiplicative error (ε). The model dependent variables included regional body mass and whole-body composition. Height was the main predictor variable with age and %fat as potential additional predictor variables (Heymsfield et al. submitted publication).

In an earlier report on the same subject sample as examined in the present study we provided an in-depth analysis of body mass scaling to height as defined by various forms of equation 1 (Heymsfield et al. submitted publication). That study provided a foundation for the current report and established that adult body mass scales to height with a power of ~2 across the US and Korean adult populations (Supplementary Table 1). Herein we report regional mass and whole-body composition scaling to height in the previously evaluated sample.

Dual-energy x-ray absorptiometry (DXA) was used to quantify body mass and the mass of four body regions and three body compartments (Figure 1). The pre-defined regional mass measurements included head, trunk, arms, and legs. The trunk region included the pelvis, ribs, and lumbar and thoracic spine. Total body mass was calculated as the sum of head, trunk, arm (right+left), and leg (right+left) mass. DXA also provided estimates of whole body fat, lean soft tissue (LST), and bone mineral content (BMC). Bone mineral content is a stable proportion of bone mass and as such represents a measure of skeletal weight (Pietrobelli et al., 1996). Thus, two parallel models of body mass (kg) were evaluated:

$$MB = \text{Head} + \text{Trunk} + \text{Arms} + \text{Legs} \quad (2)$$

$$MB = \text{Fat} + \text{LST} + \text{BMC} \quad (3)$$

Allometric analyses, with age and adiposity adjustments (Heymsfield et al., submitted publication), included the four body mass (head, trunk, arms, and legs) and two body composition measures (LST and BMC).

The study sample evaluated in primary analyses consisted of 8 subject groups (NH white, NH black, Mexican American, and Korean Asian men and women) drawn from the US National Health and Nutrition Examination Survey (NHANES) and the Korean NHANES (KNHANES) (Hong et al., 2011; Kelly et al., 2009; NHANES, 2003-4; Park, 2013).

The first analysis phase involved development of height powers (i.e., $\beta \pm SE$ in equation 1) for the six body mass and composition measures across the eight groups with the aim of establishing if there are race/ethnic differences in scaling relations. The second analysis phase involved developing power estimates for the six measures across race/ethnicity-combined men and women with the aim of evaluating between-sex differences in scaling relations.

Subjects

Details of the NHANES and KNHANES sample are provided in previous reports (Heymsfield et al., submitted publication; Hong et al., 2011; Kelly et al., 2009; NCHS, 2011; NHANES, 2003-4; Park, 2013). Subjects were entered into the data set if they were age 18 years and had a DXA evaluation. The NHANES and KNHANES survey methodology and measurement protocols are provided in Hong et al. (2011), Kelly et al. (2009), Schenker et al. (2011), and Schoeller et al. (2005). A detailed accounting of the evaluated samples is summarized in Heymsfield, et al. (submitted publication) and in Supplementary Tables 2 and 3. NHANES procedures were approved by the National Center for Health Statistics, Centers for Disease Control and Prevention and the study had human subjects approval with all participants providing written informed consent. The KNHANES protocol was approved by the Korea Center for Disease Control and Prevention Institutional Review Board and all subjects provided written informed consent.

Body Composition Assessment

The same training protocols and DXA systems were used in NHANES and KNHANES as reported in Heymsfield et al. (submitted publication) and in Hong et al. (2011), Kelly et al. (2009), NCHS (2011), and NHANES (2003-4). Regional mass and whole-body composition analysis measurement methods were reported earlier by Heymsfield et al. (Heymsfield et al., submitted publication) and in Hong et al., (2011), Kelly et al. (2009), Schenker et al. (2011), and Schoeller et al. (2005).

Statistical Methods

We performed analyses to describe regional body mass and whole-body composition scaling relations to height that are generalizable to non-institutionalized portions of the US and Korean adult (18 yrs) populations. Analyses were conducted using procedures for sample survey data in SAS® (version 9.3; SAS Institute, Cary, NC) to produce nationally representative estimates while accounting for the complex, multistage probability designs of NHANES and KNHANES. Models included sample weights to adjust for non-coverage, non-response, and oversampling of some groups. Standard errors were derived using Taylor series linearization and statistical significance was defined as $p < 0.05$ (two-tailed).

The first analysis phase included evaluation of baseline sample characteristics including total and regional body mass and body composition. Estimates for baseline characteristics were computed using PROC SURVEYMEANS and presented as mean $\pm SE$. Scaling analyses as defined by equation 1 were conducted across the eight sex (men, women) and race/ethnic groups (NH white, NH black, Mexican American, and Korean) as moderated by adiposity and age. For each of the eight sex and race/ethnic groups, separate regression

models were fitted using PROC SURVEYREG with regional body mass or whole-body composition component as the dependent variable, and height, age, and %fat as independent variables. All model variables were log-transformed (natural logarithm). Analyses were conducted using the same modeling strategy for NHANES and KNHANES; however, to account for the multiply-imputed structure of NHANES body composition data (5 imputed data sets), separate analyses were conducted for each imputed data set and the resulting estimates were averaged using PROC MIANALYZE. The scaling power (β) and corresponding standard error for height were extracted from each final model and presented as $\beta \pm SE$ (95% CI).

Between-race/ethnicity group differences in baseline characteristics and scaling powers for each sex were evaluated using Cochran's Q Test for Heterogeneity with 3 degrees of freedom (df). Follow-up analyses of significant omnibus tests were performed by computing Cochran's Q for all possible pairwise comparisons (6 comparisons with each evaluated at 1 df) while employing a Bonferroni-correction ($p < 0.05/6 = 0.0083$). Between-sex differences in regional body mass and whole-body composition scaling powers were evaluated using additional dummy-variable regressions while controlling for race/ethnicity.

For NHANES data, confidence intervals for baseline characteristics and scaling powers and critical t -statistic values for testing differences between scaling powers were derived using df calculated according to the method of Barnard and Rubin (1999). The complete-data df used in this determination was 59 (number of primary sampling units – number of sampling strata). For KNHANES data, confidence intervals for baseline characteristics and scaling powers and critical t -statistic values for testing differences between scaling powers were derived using 243 df (number of primary sampling units).

RESULTS

Subjects

Regional body mass and whole-body composition results are presented in Table 1 for each of the study sex and race/ethnic groups. Total body mass ranged from a low of 56.6 ± 0.2 kg in Korean women to a high of 89.4 ± 0.4 kg in NH white men (Supplementary Table 3). Total body fat mass was smallest in the Korean men (15.6 ± 0.1 kg) and largest in the NH black women (35.1 ± 0.4 kg). The remaining regional mass and body composition means varied in ranking across the sex and race/ethnic groups. Between-group statistical comparisons are shown in the table.

Scaling of Regional Body Mass to Height

The powers ($\beta \pm SE$) observed for regional body mass scaled to height, adjusted for age and adiposity, are summarized for the eight sex-race/ethnic groups in Table 2. The general pattern across sex and race/ethnic groups was for head mass to scale with height at the lowest rounded powers of approximately 0.8-1.0 while the highest powers were consistently observed for leg mass scaled to height with mean rounded powers of approximately 2.3-2.6 (Figure 2). Trunk and arm mass scaled to height with powers of approximately 1.8-2.3, similar to that of total body mass.

For men, significant differences in scaling powers for trunk, arm, and leg mass were observed between the four race/ethnic groups. In addition, several significant differences in scaling powers for regional body mass components were observed between race/ethnic groups among women (Table 2). There were no discernable patterns in these power differences across the four race/ethnic groups of women. The Korean women had the highest powers among the women for head and arms, an identical but non-significant pattern was observed for head mass in men.

The striking range of regional powers above and below the approximate mean power for body mass scaled to height (i.e., ~ 2) implies that body proportions differ between short and tall subjects. This effect is shown in Figure 3 for young NH white men (age 18<30 yrs). Subjects were divided into five height groups (A-E) and the lowest fifth (A) used as the reference. With greater height head mass progressively becomes a smaller fraction of the lowest fifth reference group while leg mass becomes a larger fraction of the reference group. Small decreases with greater group height are present for arm mass. Relative body mass distribution thus differed across subjects varying in stature. Since body mass scales to height with a power of 2, these findings indicate that short subjects with the same BMI as tall subjects have a relatively larger head mass and smaller leg mass.

The global height scaling power of ~ 2 for body mass observed across the groups represents the individual regional mass powers scaled to height. For example, removing leg mass from total body mass for the NH white men substantially reduced the remaining mass scaling power ($\pm$ SE) from $\sim 2.02 \pm 0.06$ to 1.87 ± 0.06 while a corresponding increase in power to 2.09 ± 0.06 is present when head mass is removed from the analysis. Smaller effects on power are present for removal of trunk (2.07 ± 0.06) and arm mass (2.03 ± 0.06) from total body mass.

Scaling of Body Composition to Height

The results of body composition scaling to height are presented in Table 2 and Figure 2 for the eight sex and race/ethnic groups. Lean soft tissue mass scaled to height with powers of approximately 2, similar to corresponding powers for body weight scaled to height. By contrast, the powers for BMC scaled to height across the eight groups were substantially higher, ranging from about 2.1 to 2.4 and were in all cases larger than those for LST. In contrast to the observed regional mass scaling relations, there were no significant between-group differences in whole-body composition scaling powers among the race/ethnic groups in men but some significant BMC power differences in women.

Since BMC scaled to height with powers exceeding 2, bone was a larger fraction of body mass even in subjects with the same BMI.

Comparisons Between Men and Women

The scaling powers of height for regional mass and whole-body composition observed for race/ethnicity-combined US and Korean men and women are presented in Table 3 and Figure 4. With respect to the scaling of regional mass to height, a very similar pattern was again present in both men and women: head mass scaled with the lowest rounded powers (~ 0.8 -1.0), legs with the largest rounded powers (~ 2.3 -2.4), and trunk and arms with

intermediate powers (~1.9-2.2) similar to that of body mass (Supplementary Table 1). Powers also again tended to be larger in men than women with significant or borderline significant sex differences present for head (NHANES), trunk (NHANES and KNHANES), and arms (NHANES and KNHANES).

Lean soft tissue mass scaled to height with powers similar to those of body mass (~2.0-2.1) while BMC scaled to height with substantially larger powers (~2.3-2.4) in the men and women (Figure 4). The powers of LST scaled to height were larger in men than in women, approaching statistical significance ($p < 0.1$) in the NHANES sample.

DISCUSSION

Body mass index is now used as a global measure of adiposity and health, although not without controversy surrounding the mathematical construct as first stimulated by Quetelet's 1842 observation that adult body mass scales as height squared (Benn, 1971; Bogin, 2008; Burton, 2007; Cole, 1991; Diverse Populations Group, 2005; Garn et al., 1986; Green, 2009; Keys et al., 1972; Larsson et al., 2006; Samras, 2007; Smalley et al., 1990; Trefethan, 2013). A comprehensive earlier report from our group showed that in the carefully evaluated and analyzed large NHANES and KNHANES samples body mass does indeed scale to height across adult sex and race/ethnic groups with powers very close to 2 (Heymsfield et al., submitted publication). The current report describes the next stage in exploring scaling relations on the pathway to evaluating race/ethnic differences in body shape and composition while additionally seeking an overall mechanistic understanding of why adult human body mass scales to height with a power of 2.

Body Shape

Our findings, the first of their type, show that regional mass height scaling powers display a distinct pattern across the eight evaluated sex and race/ethnic groups: head < trunk and arms < legs with respective rounded powers of approximately 1, 2, 2, and 2.5. As body mass scales as Ht^2 , tall adult humans have heads that are relatively smaller in mass and legs that are relatively larger in mass than in subjects who are short; arms and trunk remain approximately stable proportions of body mass. At the same BMI, tall adults differ in regional mass proportions from their shorter counterparts. At the whole-body composition level, LST scaled to height with powers similar to that of body mass while BMC, a representation of skeletal mass, scaled with powers larger than 2 (i.e., ~2.1-2.4). Accordingly, skeletal mass is a larger fraction of body mass in tall adults compared to their short counterparts. These scaling patterns were remarkably consistent across all evaluated sex and race/ethnic groups.

The varied regional mass scaling relations are “masked” by the global scaling of body mass to height with a power of approximately 2. If tall “large” adults are isometric copies of short “small” adults then body mass would scale approximately as Ht^3 as is often implied or assumed (Burton, 2007; Samras, 2007; Trefethan, 2013). Our findings firmly establish that BMI, based on body mass scaling as height squared, reflects a previously unforeseen heterogeneous regional body mass and composition scaling pattern.

As in our previous report (Heymsfield et al., submitted publication) and those of others (Burton, 2007), regional mass and body composition height scaling powers in women generally were smaller in magnitude than those observed in men, although the statistical significance of these differences was inconsistent. One explanation for these sex differences is that the greater anabolic stimulus males experience during puberty may lead to greater relative body mass at any level of stature compared to women (Rogol, 2003). While this sex difference pattern was consistent across all evaluated compartments, the estimated power differences tended to be small and did not detract from the larger aforementioned regional mass and body composition scaling patterns that were consistent across sex and race/ethnic groups.

Power differences across race groups tended to be relatively small and did not appear to fall into any consistent discernable patterns. The one finding that appears to represent a subtle specific race/ethnic effect was that head and arm mass scaled to height with larger powers in Korean women than in other race/ethnic groups of women. Additional in-depth analyses are needed to establish the significance of these race/ethnic differences in body shape.

Mechanistic Associations

We have now established that with greater body size, as defined by stature, adult humans have a relatively smaller fraction of their mass as head and larger fractions as legs and skeleton; arms, trunk, and LST remain relatively stable proportions of body mass independent of height. Analysis of the basis for this pattern can take many directions and focus at different organizational levels.

An example is presented for the distinct scaling pattern observed for head mass (M_H) as $\propto Ht^{-1}$. Earlier studies report that brain mass also scales to height across adults with powers of 1 or less (Heymsfield et al., 2004, 2007, 2009). These observations suggest that brain and head mass scale similarly to height and are concordant with the vast anthropological literature linking brain volume to skull features (Lieberman, 2011; Vannucci et al., 2011). Moreover, recent studies of microcephalic humans and Zebrafish with induced counterpart mutations show that skull development mirrors reduced brain growth (Dauber et al., 2012). Skull and head mass grow to accommodate an enlarged intracranial volume with early-life hydrocephaly features (Lieberman, 2011). Changes in head mass as a function of body size thus appear concordant with corresponding findings for brain mass and molecular/biomechanical mechanisms may account for this association.

Human growth progresses in a cephalocaudal direction with major head and brain growth both reaching peak levels during the first decade of life while substantial somatic growth continues and accelerates during adolescence (Keenan, 2002). Different molecular and hormonal control mechanisms, at least in part, thus regulate growth of the head and other body regions. The observed scaling pattern with head and that was observed earlier for brain (Heymsfield et al., 2004, 2007, 2009) is consistent with the morphogenic pattern for humans depicted by Stratz (1909) and Scammon (1930) in which head size and neurological tissue progressively become smaller fractions of body mass with growth from birth onward. Our findings based on static allometric relations in fully grown adults suggest that the head is

part of this continuum with greater body size accompanied by relatively heavier, and presumably longer, legs and a proportionally smaller head mass.

Brain is a high-energy expenditure organ, consuming 240 kcal/kg/day or about 20% of adult resting energy expenditure (REE; Gallagher et al., 1996). Since brain mass scales as Ht^{-1} and REE as $Ht^{-1.5}$, tall adults have a lower mass-specific REE relative to their short counterparts (i.e., $Ht^{-0.5}$). Low energy expenditure relative to body mass, after adjusting for adiposity, may convey metabolic advantages such as greater fasting endurance to tall subjects (Heymsfield et al., 2009). Had brain and related head mass scaled as Ht^2 or even Ht^3 , the additional energy and thus dietary needs would be substantial. Since human brain growth largely ceases at least one decade before somatic growth, it is not surprising that brain mass contributes independently to adult REE even after controlling for the metabolically active fat-free mass compartment (Heymsfield et al., 2014). Head scaling to body size with a power of 1 can thus be connected through a series of potential linkages to human energy requirements.

While these analytical threads may be tenuous, we show here how Quetelet's Rule embraces another rule ($M_H \propto Ht^{-1}$) and that rule can be associated with an array of related biological processes.

Study Limitations

While DXA provides an important approach for measuring regional body mass, the question remains how these estimates correspond to body lengths. Bone lengths can be measured directly from the DXA scan and it would be possible in future biomechanics studies to establish how our regional mass-related findings integrate with the many anthropological length ratios that are in widespread use (Bogin and Varela-Silva, 2008, 2010, 2012). A second concern and proviso is that our results may not be generalizable to all race/ethnic groups. For example, Korean Asians may differ in body shape and composition from their counterparts in other Asian nations. Lastly, many earlier comprehensive studies link adult body proportions to environmental influences experienced during the growth period (Bogin and Varela-Silva, 2010, 2012). To the extent factors such as socioeconomic status and nutritional adequacy influence the evaluated scaling relations remains unknown and a topic worthy of future study.

Summary and Conclusions

At the outset our goal was to further explore BMI as a measure of adiposity and health across sex and race/ethnic groups amid the controversy surrounding body mass scaling to height with a power of 2 and that the empirical relation $MB \propto Ht^2$ lacks a theoretical context. Further, even after adjustment for stature, body mass appears to be only an approximate metric of an individual's body composition across sex and race/ethnic groups (Gallagher et al., 1996). Accordingly, we laid out a series of investigations centered on the unique NHANES and KNHANES data sets that address these concerns. Our first report firmly established that with greater body size, as defined by stature, body mass empirically scales to adult height across sex and race/ethnic groups narrowly around a power of 2 (Heymsfield et al., submitted publication). The current study extended these earlier efforts

and establishes that Quetelet's Rule represents a series of related structural and body composition rules that can initially be framed in a broader biological context. The newly discovered static allometric scaling pattern was consistent across all evaluated sex and race/ethnic groups. With these collective observations as a foundation, the next phase of research addressing BMI as a universal health marker is two-fold: exploring potential mechanisms for the newly established adult body size scaling pattern; and in the context of BMI, conducting in-depth analyses of race/ethnic differences in body shape and composition, an important opportunity provided by the available methodologically-rigorous NHANES-KNHANES database.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

BMI	body mass index
BMC	bone mineral content
CI	confidence interval
df	degrees of freedom
DXA	dual-energy x-ray absorptiometry
Ht	height
KNHANES	Korean National Health and Nutrition Survey
M_B	body mass
Mex Amer	(Mexican American)
NH	non-Hispanic
NHANES	National Health and Nutrition Survey
SD	standard deviation
SE	standard error
US	United States

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Figure 1.

The evaluated regional body mass and whole-body composition regions are shown superimposed on a representative DXA scan. At the whole-body level, body mass (M_B) represents the sum of head (H), trunk (Tr), arm (Ar), and leg mass. At the molecular level, M_B represents the sum of total body fat, lean soft tissue (LST), and bone mineral content (BMC) mass.

Figure 2.

Results for regional mass scaling powers (upper panel) and body composition powers (lower panel) observed for NHANES and KNHANES participants. Results are mean $\pm$ SE. Powers for body mass scaling are from Heymsfield et al. (submitted publication; Supplementary Table 1). A horizontal line is shown in each figure at a power of 2. Abbreviations: BMC, bone mineral content; LST, lean soft tissue; Mex, Mexican; NH, non-Hispanic. Statistical comparisons between the groups are shown in Table 2.

Figure 3.

Fraction of body mass as each of four regions (head, trunk, arms, legs) across non-Hispanic (NH) white men $18 < 30$ years of age ranked by height divided into fifths (A-E; $n=918$) and expressed as the ratio to the lowest fifth (A).

Figure 4.

Nationally representative (NHANES and KNHANES) results for regional mass scaling powers (mean $\pm$ SE) in the upper panel and body composition scaling powers (mean $\pm$ SE) in the lower panel. Powers for body mass scaling are from Heymsfield et al. (submitted publication; Supplementary Table 1). Horizontal lines are shown in the figure at a power of 2. Statistical comparisons between the groups are shown in Table 3. Abbreviations: BMC, bone mineral content; LST, lean soft tissue.

Table 1

Subject DXA Scan Regional Mass and Body Composition Results.

	Men					Women				
	NH white	NH black	Mex Amer	Korean	p	NH white	NH black	Mex Amer	Korean	p
N	4406	2035	2256	3851		4235	2045	2149	5091	
Body Mass(kg)										
Total	89.4±0.4 ^a	89.1±0.6 ^a	81.6±0.6 ^b	69.4±0.2 ^c	< 0.001	74.7±0.4 ^a	83.9±0.5 ^b	72.8±0.6 ^a	56.6±0.2 ^c	< 0.001
Head	5.19±0.01 ^a	5.43±0.02 ^b	5.08±0.02 ^c	5.44±0.02 ^b	< 0.001	4.33±0.01 ^a	4.84±0.02 ^b	4.48±0.02 ^c	4.64±0.01 ^d	< 0.001
Trunk	44.6±0.2 ^a	41.5±0.3 ^b	40.7±0.3 ^b	33.9±0.1 ^c	< 0.001	36.6±0.2 ^a	39.0±0.3 ^b	36.5±0.3 ^a	27.9±0.1 ^c	< 0.001
Arms	11.12±0.05 ^a	11.66±0.08 ^b	10.23±0.08 ^c	7.74±0.03 ^d	< 0.001	8.23±0.05 ^a	9.78±0.07 ^b	8.17±0.08 ^a	5.75±0.02 ^c	< 0.001
Legs	28.5±0.1 ^a	30.5±0.2 ^b	25.5±0.2 ^c	22.3±0.1 ^d	< 0.001	25.5±0.1 ^a	30.2±0.2 ^b	23.7±0.2 ^c	18.2±0.1 ^d	< 0.001
Body Composition(kg)										
Fat Mass	26.0±0.2 ^a	23.8±0.3 ^b	23.4±0.3 ^b	15.6±0.1 ^c	< 0.001	30.5±0.3 ^a	35.1±0.4 ^b	30.3±0.4 ^a	18.8±0.1 ^c	< 0.001
LST	60.6±0.2 ^a	62.3±0.3 ^b	55.6±0.3 ^c	53.9±0.2 ^d	< 0.001	42.0±0.1 ^a	46.4±0.2 ^b	40.5±0.2 ^c	37.7±0.1 ^d	< 0.001
BMC	2.75±0.01 ^a	2.99±0.02 ^b	2.50±0.01 ^c	2.60±0.01 ^d	< 0.001	2.11±0.01 ^a	2.33±0.01 ^b	2.03±0.01 ^c	2.01±0.01 ^c	< 0.001

Results are mean±SE. Abbreviations: BMC, bone mineral content; NH, non-Hispanic; LST, lean soft tissue; Mex Amer, Mexican American. Between-race/ethnicity comparisons performed using Cochran's Q Test for Heterogeneity. Values with different superscript letters are significantly different at $p < 0.05/6 = 0.0083$.

Table 2

Results of Allometric Analyses.

	Men				Women			
	NH White	NH Black	Mex Amer	Korean	NH White	NH Black	Mex Amer	Korean
Body Mass								
	2.02±0.06	2.29±0.09	2.14±0.07	2.11±0.06	1.97±0.06	1.94±0.08	1.99±0.09	1.99±0.06
	1.91-2.14	2.10-2.48	2.01-2.27	1.99-2.23	1.85-2.09	1.77-2.10	1.82-2.17	1.87-2.10
Head								
	0.91±0.04	0.98±0.07	0.87±0.06	1.00±0.05	0.81±0.04 ^a	0.78±0.07 ^{ab}	0.75±0.05 ^a	0.97±0.04 ^b
	0.82-1.00	0.84-1.11	0.74-0.99	0.90-1.09	0.72-0.90	0.64-0.91	0.65-0.85	0.89-1.06
Trunk								
	1.97±0.06 ^a	2.32±0.10 ^b	2.01±0.08 ^{ab}	2.06±0.07 ^{ab}	1.93±0.07	1.91±0.10	1.84±0.10	1.92±0.07
	1.85-2.10	2.12-2.52	1.85-2.16	1.92-2.21	1.79-2.07	1.70-2.12	1.62-2.05	1.79-2.05
Arms								
	1.96±0.06 ^a	2.27±0.12 ^{ab}	2.12±0.09 ^{ab}	2.23±0.07 ^b	1.84±0.08	1.87±0.11	1.84±0.11	2.09±0.08
	1.83-2.09	2.03-2.50	1.94-2.29	2.09-2.38	1.68-2.00	1.63-2.10	1.62-2.06	1.94-2.24
Legs								
	2.34±0.06 ^a	2.49±0.10 ^{ab}	2.61±0.07 ^b	2.41±0.07 ^{ab}	2.29±0.06	2.21±0.08	2.54±0.10	2.34±0.06
	2.22-2.46	2.29-2.70	2.46-2.75	2.28-2.54	2.17-2.41	2.04-2.39	2.33-2.74	2.22-2.46
Body Composition								
LST								
	2.04±0.05	2.26±0.09	2.11±0.06	2.11±0.06	1.97±0.05	1.96±0.08	1.99±0.09	2.01±0.06
	1.93-2.14	2.07-2.44	1.98-2.24	1.99-2.23	1.86-2.08	1.79-2.13	1.81-2.17	1.90-2.13
BMC								
	2.26±0.05	2.40±0.10	2.29±0.08	2.32±0.07	2.32±0.05 ^a	2.09±0.06 ^b	2.37±0.07 ^a	2.43±0.07 ^a
	2.16-2.37	2.19-2.61	2.13-2.45	2.19-2.46	2.21-2.42	1.96-2.22	2.23-2.52	2.30-2.57

Powers are expressed as $\beta \pm SE$ with 95% CI below. Abbreviations: BMC, bone mineral content; NH, non-Hispanic; LST, lean soft tissue; Mex Amer, Mexican American. Between-race/ethnicity comparisons performed using Cochran's Q Test for Heterogeneity. Values with different superscript letters are significantly different at $p < 0.05/6 = 0.0083$.

Table 3

Nationally Representative Scaling Powers.

	NHANES		KNHANES		$\beta^{\dagger}$
	Men	Women	Men	Women	
Sample N	9406	9192	3851	50918	
Regional Mass					
Head	0.92 $\pm$ 0.04	0.80 $\pm$ 0.03	0.99 $\pm$ 0.05	0.97 $\pm$ 0.04	0.02 $\pm$ 0.06
	0.84-1.00	0.73-0.87	0.90-1.09	0.89-1.06	-0.09-0.13
Trunk	2.09 $\pm$ 0.05	1.97 $\pm$ 0.05	2.06 $\pm$ 0.07	1.92 $\pm$ 0.07	0.14 $\pm$ 0.09
	1.99-2.19	1.87-2.07	1.92-2.21	1.79-2.05	-0.04-0.33
Arms	2.07 $\pm$ 0.05	1.87 $\pm$ 0.06	2.23 $\pm$ 0.07	2.09 $\pm$ 0.08	0.15 $\pm$ 0.10
	1.96-2.17	1.76-1.99	2.09-2.38	1.94-2.24	-0.04-0.34
Legs	2.42 $\pm$ 0.05	2.37 $\pm$ 0.05	2.41 $\pm$ 0.07	2.34 $\pm$ 0.06	0.08 $\pm$ 0.09
	2.32-2.52	2.27-2.46	2.28-2.54	2.22-2.46	-0.10-0.25
Body Composition					
LST	2.12 $\pm$ 0.04	2.01 $\pm$ 0.04	2.11 $\pm$ 0.06	2.01 $\pm$ 0.06	0.10 $\pm$ 0.08
	2.03-2.20	1.93-2.10	1.99-2.23	1.90-2.13	-0.06-0.25
BMC	2.31 $\pm$ 0.04	2.31 $\pm$ 0.04	2.32 $\pm$ 0.07	2.43 $\pm$ 0.07	-0.11 $\pm$ 0.09
	2.22-2.39	2.22-2.40	2.19-2.46	2.30-2.5	-0.30-0.08

 $\dagger$, difference between men and women. Results are $\beta \pm$ SE with 95% CI.*
p<0.05.