The Interrelationship between Body Topology and Body Composition Varies with Age among Women

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ABSTRACT The purpose of this analysis was to evaluate the relationship between age and the size and distribution of the fat and lean tissue compartments in a population-based sample of women. The study population consisted of the 875 women aged 18–94 y in the Iowa Bone Health Study who reported never smoking. Fat mass and lean mass were measured using dual X-ray absorptiometry. Hip and waist circumference and height were measured using standardized protocols. Regression was used to model the associations among age, composition and topology measures. When fat mass was modeled as a function of hip and waist circumference as well as age, age and height, the age × height and age × waist circumference interaction terms remained in the fitted model and collectively accounted for 91% of the variance. In contrast, the quadratic model of age alone accounted for 8% of the observed variance in fat mass. Lean mass was modeled in two segments, with age dichotomized at 58 y. Age alone did not predict lean mass in women <58 y but did predict lean mass in women ≥58 y, with the modeled relationship including interactions with waist circumference and height. These models accounted for 70% of observed variance in lean mass. Age is associated with body composition but explains <10% of variation. When measures of height and circumferences are available, amounts of lean and fat mass are highly predictable. This is particularly important for lean mass because no other surrogate measures exist for lean mass, whereas there are surrogates for fat mass, including body mass index. J. Nutr. 130: 2371–2377, 2000.

KEY WORDS: fat mass • lean mass • dual X-ray densitometry • body composition • body circumference measures

Surrogate measures of body composition and topology (approximated by measures such as body mass index and waist/hip ratio, respectively) have been linked to mortality and chronic diseases. Additionally, measures of body composition and body topology are related to undesirable metabolic characteristics that are known risk factors for chronic diseases, such as glucose intolerance, hyperinsulinemia, elevated triglycerides and low HDL cholesterol concentrations (Jensen 1997, Kissebah and Krakower 1994).

Although these surrogate measures of body composition and body topology are sometimes portrayed as interchangeable, they represent different, though related underlying constructs. Body composition measures are estimates of the amount of mass of a specific body compartment (i.e., fat and lean), whereas topology measures are proxies for the locational distribution of gluteal and visceral adipose tissue. In epidemiologic research, questions remain concerning whether the two types of measures are independent predictors of chronic disease risk or whether there are combined effects of body composition and body topology that affect the ability of either to predict disease risk independently. Because age is a major marker for most chronic diseases, an understanding of the interaction of body composition and body topology with age could advance our understanding of the interpretation of studies in which surrogate measures of body composition are used. Some effects of aging on body composition or body topology, notably loss of muscle mass in the elderly (Rosenberg and Roubenoff 1995) or more central adiposity after menopause (Kotani et al. 1994, Zamboni et al. 1997) are relatively well documented. However, few studies have addressed the effect of chronological age on the association between actual measures of body composition and topology.

The purpose of this analysis was to evaluate the relationships between age and the size and distribution of the fat and lean tissue compartments in a population-based sample of heterogeneously aged women. The following three questions were addressed: 1) What is the proportion of measures of body composition and body topology that can be explained by age? 2) If the sizes of the compartments can be described as a function of age, what are the shapes of those functions? 3) Does age affect the predictive relationship between body topology measures and the sizes of the fat and lean compartments?

SUBJECTS AND METHODS

Population. Data were collected in 1993–1994 from 1300 women, aged 18–94 y, who were residents of three Iowa communities, selected for the unique mineral characteristics in the community water supply. Each community is similar with respect to size (<2000 residents per community), ethnic characteristics (primarily Anglo-Saxon and Germanic), including the number of foreign born, mean income and primary occupations. In 1993–1994, a census of commu-
mass index (BMI, kg/m2) was calculated. There were 18 subjects nated before measurement for weight. From these two measures, body preimplementation training. Women had not been fasting, but uri-

The average age of subjects with recorded height differences decreased). For these subjects, height measures were set to missing. At 3 cm or more between the 1993–1999. Scans with technical problems were either sent to the man-

Data collection. Body composition measures. Body composition, including fat mass and lean mass (excluding bone mineral content) compartments, was measured using dual X-ray absorptiometry (DXA-Lunar Corporation, Madison, WI, DEXA-L, software version 1.3y). Two certified technicians scanned each enrollee for total body bone mineral density, a measure that was accompanied by body composition information including lean mass, fat mass and bone mineral content (Elowsson et al. 1998, Kamel et al. 1999, Lukaski et al. 1999). Scans with technical problems were either sent to the man-

Height was measured using an anthropometric plane and scale to the nearest 0.1 cm and weight was taken to the nearest 0.1 kg, after preimplementation training. Women had not been fasting, but urin-

The average age of subjects with recorded height differences >3 cm was 57.7 ± 4.5 y (mean ± SEM) compared with 54.9 ± 0.5 y for subjects whose measured height changed <3 cm (P = 0.52).

Waxt circumference (cm) was measured as the smallest location of the midsection and was undertaken following a forced expiration. Hip circumference (cm) was measured at the location of the greatest gluteal mass. All measures were taken using a nonstretching tape over a single layer of light clothing.

Because of the well-known, if not well-understood effects of smoking on body weight and metabolism (Grunberg et al. 1992, Wack and Rodin 1982), only data from participants who reported never smoking were used in these analyses. Of the 1300 baseline participants, 876 were never-smokers and thus were eligible for inclusion in the analyses. The average age of current smokers (45 ± 1.3 y) was about a decade younger than never and former smokers (57 ± 0.6 and 56 ± 1.2 y, respectively), (P < 0.0001). Women who had ever used oral contraceptive agents (n = 54) or hormone replacement therapy (n = 19) were included because preliminary investigation indicated that the use of these preparations was not associated with variation in the body composition measures.

Not all age-eligible women had all body composition measurements taken. One woman refused DXA and anthropometric measurement and was not included in the analyses. In addition, there were 68 participants without DXA data whose anthropometric data were included in descriptive statistics but not in the regression models. The average weight of participants without DXA scans was 92.6 ± 2.8 kg compared with 72.2 ± 0.5 kg for those who were scanned (P < 0.0001). The participants without scans also had significantly greater mean hip and waist circumferences (P < 0.0001); they were ~4.5 y older than the group with DXA scans (P = 0.07).

Statistics. The body composition data were modeled as two compartments, fat mass and lean mass, including body fluids and muscle mass (but excluding bone mineral content). The data were evaluated for distribution characteristics and did not require the use of transformations to address the assumptions of an underlying normal distribution. Linear regression analyses were used to model body compartment sizes as a function of age. Age was included in these models as a continuous variable. Because curvilinear models were evaluated, all models initially included an age^2 as well as the age term. For models including age^2, mean age was subtracted from age before the calculation of age^2 to remove the colinearity between the age and age^2 terms. The hip and waist circumferences and height were evaluated as main effect terms and were included in interaction terms with age in the regression models. The significance level was defined as α < 0.05. The range of effects of many independent variables on an outcome, as characterized by the multiple variable regression models, was depicted with conditioning display methodolog-

Weight was not included in the regression models for this investi-
gation because weight was conceptualized as the sum of outcomes (fat mass + lean mass without bone + bone mass) rather than as an independent predictor of compartment size. Further, this paper addresses the absolute lean and fat body composition compartments, rather than BMI, because BMI is a surrogate for body fat, but not for percentage of body fat as shown in Figure 1A and B.
RESULTS

A histogram of the number of participants according to 5-7 age groupings is shown in Figure 2. The physical characteristics of the study sample are shown stratified by age groupings in Table 1. The data are shown according to percentiles within four age groups to facilitate comparison with distributions of values in other populations, most notably the 85th percentile value used by the National Center for Health Statistics to describe obesity with data from the National Health and Nutrition Examination Surveys (Kuczmarski et al. 1994).

As expected, fat mass was correlated with weight and BMI (Table 2). Percentage of body fat, BMI and fat mass (kg) were not interchangeable in their association with each other (Fig. 1A and B). Therefore, this report focuses on fat mass (kg). There were lower correlations between lean mass and weight and lean mass and BMI (Table 2). There were high correlations between fat mass and waist and hip circumferences, whereas there were lower correlations between lean mass and waist and hip circumferences.

Figures 3–6 represent the relation of age to measures of body composition (fat mass and lean mass) and to measures of body topology (waist circumference and hip circumference). The relationship between fat mass and age and the circumpereleasure measures and age could be summarized with quadratic models. Figures 3–5 depict the fitted age + age² polynomial model for each measure accompanied by the 95% prediction intervals for the fitted line. According to these single variable models, fat mass increased gradually with increasing age until ~56 y at which time the mass of the fat compartment started to decrease. Waist circumference increased steadily with age throughout young adulthood and middle age and then declined slowly after 67 y. Hip circumference values also increased in young adulthood and middle age, reaching their highest average value at age 56 y. The relationship between lean mass and age (Fig. 6), however, was best described using two separate regression lines, one for subjects <58 y and one for those ≥58 y.

![FIGURE 2](image.png)

Age distribution of the 875 nonsmoking women included in the analysis of the relationship between body topology and body composition.

**TABLE 1**

Percentile distribution of height, weight, body composition and body topology measures in 875 nonsmoking women age 18–94 y: Iowa Bone Health Study, 1994

<table>
<thead>
<tr>
<th>Measure</th>
<th>Age group, y</th>
<th>n</th>
<th>Percentile</th>
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<tbody>
<tr>
<td></td>
<td>15 33 50 66 85</td>
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<tr>
<td>Height, cm</td>
<td>17–42</td>
<td>250</td>
<td>158 162 165 168 172</td>
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<td></td>
<td>43–62</td>
<td>216</td>
<td>157 160 163 165 169</td>
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<td>76–99</td>
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<td>151 154 156 159 163</td>
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<tr>
<td>Weight, kg</td>
<td>17–42</td>
<td>250</td>
<td>57 63 69 76 91</td>
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<td>43–62</td>
<td>218</td>
<td>60 68 75 85 99</td>
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<td>63–75</td>
<td>233</td>
<td>61 67 73 85 88</td>
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<td></td>
<td>76–99</td>
<td>173</td>
<td>54 61 67 72 81</td>
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<tr>
<td>Body mass index, kg/m²</td>
<td>17–42</td>
<td>250</td>
<td>21 23 25 28 32</td>
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<td></td>
<td>43–62</td>
<td>216</td>
<td>23 26 29 31 37</td>
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<td></td>
<td>76–99</td>
<td>168</td>
<td>23 25 27 29 32</td>
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<tr>
<td>Waist circumference, cm</td>
<td>17–42</td>
<td>250</td>
<td>71 76 80 86 98</td>
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<td>43–62</td>
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<td>77 83 90 97 109</td>
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<td>79 84 90 95 103</td>
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<tr>
<td>Hip circumference, cm</td>
<td>17–42</td>
<td>250</td>
<td>97 102 106 110 118</td>
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<td>43–62</td>
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<td>100 105 110 116 126</td>
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<td></td>
<td>76–99</td>
<td>173</td>
<td>96 110 105 110 119</td>
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<td>Fat mass, kg</td>
<td>17–42</td>
<td>234</td>
<td>15 20 24 29 37</td>
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<td>43–62</td>
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<td>63–75</td>
<td>221</td>
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<td>76–99</td>
<td>150</td>
<td>17 21 26 29 34</td>
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<td>Lean mass, kg</td>
<td>17–42</td>
<td>234</td>
<td>37 39 41 43 48</td>
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<td>43–62</td>
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Multiple variable regression models for fat mass. The quadratic model of fat mass predicted by age in Figure 3 accounted for \(0.8\%\) of the variance \((P, 0.05)\) in the data. When measures of height and body topology were also considered in the modeling, in addition to age, the terms for waist circumference, hip circumference, height and two interaction terms (age \(\times\) waist circumference and age \(\times\) height) were significant. This model accounted for \(91\%\) of the variation in fat mass; the terms in the final model are presented in Table 3.

The presence of the squared and interaction terms indicates that predicted fat mass levels are dependent not only on the predictor variables (i.e., height) but also on the differences among these predictors. The plots in Figure 7 show fat mass predicted by the multiple variable fat mass model over the nonextreme ranges (5th–95th interquartile range) of observed age and waist circumferences and at the 33rd, 50th and 85th percentile values of height and hip circumference. By depicting the model in this dynamic fashion, it is possible to demonstrate the predicted value of fat mass over many different sets of predictors simultaneously and to gain insight from the model. The relationships shown in Figure 7 were consistent with Figures 3–6, which indicate that both the predictors and outcomes changed with age.

Multiple variable regression models for lean mass. The two piecewise regression models predicting lean mass from age 18 to 57 y and 58 to 94 y are presented in Table 3. In the single variable model, the use of age did not predict lean mass in the younger (<58 y) age group; however, when body topology and height were included in the multiple variable model, age was a significant predictor of lean mass. The final multiple variable model for lean mass in subjects >58 y old accounted for 71% of the observed variance in the model. Above age 57 y, the modeled relationship between age and lean mass was more complex; the final model for lean mass in subjects >58 y old included interaction terms for age \(\times\) waist circumference and age \(\times\) height in addition to the anthropometric measures of lean mass. This portion of the piecewise regression accounted for 69% of the variance in lean mass. Similar relationships were observed when fat-free mass (lean mass plus bone mineral content) was evaluated.

DISCUSSION

In this cross-sectional study, the relationships of three measures (height, waist circumference and hip circumference) to both fat and lean mass were investigated along with the effects...
of age on those relationships. Fat mass was relatively well predicted by weight, BMI or waist circumference; however, lean mass was not well predicted by surrogate measures. If lean mass is important in disease, it will have to be measured directly. Ironically, lean mass is a much less studied compartment relative to the risk for chronic diseases than fat mass. Yet two studies (Salamone et al. 1996, Sowers et al. 1992) have shown that lean mass is more strongly associated with bone mineral density than is fat mass. Further, it is in the muscle mass, rather than the fat mass, that efficient carbohydrate metabolism takes place.

The simple regression models considering age and age\(^2\) in relation to body topology fat mass had highly significant overall P-values. It could be surmised that measures of body composition and body topology change with age in a curvilinear manner; this generalization, however, did not hold for lean mass, which was best modeled as a two-piece line, flat and then declining. The concave-shaped relationship between fat mass and age in women seen in Figure 2A has been reported by several other authors who used four-compartment elemental analysis (Aloia et al. 1996, Ellis 1990), two-compartment bioelectrical impedance (Silver et al. 1993) and two-compartment DXA analyses (Mautalen et al. 1996, Mott et al. 1999).

Although age was related to both fat mass and body topology, the age at which the apex of the curves was observed was not the same for each of the measures. This result suggested that even if these constructs were correlated biologically, they had different trajectories and were not behaving similarly. The data presented were consistent with loss of muscle mass of the elderly identified as sarcopenia (Rosenberg and Roubenoff, 1995). These data also suggested that the time interval between 40 and 55 y reflected substantial transition and Roubenoff, 1995). These data also suggested that the time interval between 40 and 55 y reflected substantial transition

In contrast to observations in lean mass, age modified the effect of both waist circumference and height in the multiple variable lean mass model, we had hypothesized that an age \(\times\) height interaction would reflect two groups. The first group would have included those who were shorter in the young adult and middle-aged group. A second group would have included those who had greater height as young adults and middle-aged women, but who had lost height with aging and become "short" because of spinal compression and/or vertebral crush fractures (height is a recognized risk factor for osteoporosis). We speculated that we might observe that young adult and middle-aged shorter women had more muscle per unit height than the taller women, but were more likely to lose that greater muscle mass per unit height in older age. This hypothesis, however, was not substantiated by the data (not shown).

In the fat mass model, the slope of the waist effect became less steep as age increased. The two variable regression models (Figs. 3, 4) provide one possible explanation for these results. Although fat mass (Fig. 3) reached its peak and began to decline at age 56 y, waist circumference (Fig. 4) peaked at age 67 y and declined at a negligible rate after that. Therefore, the outcome (fat mass) and predictor (waist circumference) were not changing at the same rate. Changing abdominal tissue distribution with increasing age may be one possible explanation for this finding. An additional possible explanation hypothesized by Spencer and Clive (1996) is "senescent convergence," i.e., extreme values of body size, chemistry or function converge with increasing age.

**Considering sources of measurement error.** Caution should be exercised in extrapolating the aforementioned relationships in obese or morbidly obese populations, although surprising given that the waist and hip circumferences are usually considered surrogate markers for gluteal or abdominal fat depots.

Among the older age group in the second segment of the multiple variable lean mass model, we had hypothesized that an age \(\times\) height interaction would reflect two groups. The first group would have included those who were shorter in the young adult and middle-aged group. A second group would have included those who had greater height as young adults and middle-aged women, but who had lost height with aging and become "short" because of spinal compression and/or vertebral crush fractures (height is a recognized risk factor for osteoporosis). We speculated that we might observe that young adult and middle-aged shorter women had more muscle per unit height than the taller women, but were more likely to lose that greater muscle mass per unit height in older age. This hypothesis, however, was not substantiated by the data (not shown).

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DXA is considered an accurate means of assessing body composition (precision error < 2%) (Casey, 1999, Hansen, 1999) and is highly correlated with hydrodensitometry (underwater weighing) values. Dual X-ray densitometry cannot be undertaken in the morbidly obese because the scan table is mechanically stable only to weights between 118 and 132 kg (260–290 pounds) (depending upon the manufacturer). It deforms with loads beyond those weights, jeopardizing the entire system. Among the subjects without scans in this investigation, seven women exceeded the 120 kg (260 pounds) limit for the DXA machine used. Second, an underlying assumption of DXA use is that measurements are not affected by the anteroposterior thickness of the body. However, studies have shown consistently that body thickness > 25 cm does have an effect on evaluating the energy signal, typically leading to overestimates of the fat mass.

Measuring fat and lean compartment size with DXA is based on the assumption that fat-free mass hydration remains constant over all ages. The testing of this assumption is particularly important because these data suggest that the fat and lean compartments do change in mass as a function of age. Although Pietrobelli et al. (1996 and 1998) provided theoretical and experimental evidence that DXA fat mass estimates are sensitive to fat-free mass hydration, it is reassuring that the size of the error is extremely small, <1% with hydration changes between 1 and 5%. Schoeller (1989) concluded that total body water decreases with age, but hydration of fat-free mass remains relatively constant. In their review of the literature, Wang et al. (1999) concluded that the assumption of constancy of fat-free mass hydration can be assumed only for nonelderly adults; however, any difference in fat-free mass hydration with senescence is likely to be small.

Last, the estimation of body composition is a function of the 40–50% of the pixels that do not contain bone, and the fewer the pixels available to provide data, the larger the measurement error is likely to be. Thus, if investigators are more interested in the measurement of regions of the body, including the thorax and arm that may have relatively fewer pixels without bone, they should anticipate that body composition data from those regions are more likely to be prone to measurement error.

There were potential sources of error in the measurement of body topology. Although standardized protocols were used to measure the waist and hip circumferences used in this analysis, not all sources of variability (some of them age dependent) could be eliminated when the data were being collected. The location of the waist moves up and down with changes in weight and muscle tone (Baumgartner et al. 1988); typically, therefore, long-term reproducibility could be a problem. Both waist and hip circumferences included fat, lean, bone, skin, and, in the case of waist circumference, organ tissues as well. Changes in any of these tissue compartments with age would be included in the circumference measurements but would not necessarily be reflective of changes in the specific composition department being predicted. Hip circumference might have been affected by measurement modifications due to pelvic size and shape.

Inferences with biological relevance. The results of these analyses were based on cross-sectional data; thus, no assumptions about rates of change over age can be made. However, cohort effects can be ruled out as a reason for different compartment sizes in different ages among the study subjects, then the analysis of the data suggests that in this population of women, both the fat and lean compartments change in size over the age span.

In the case of the fat compartment, the age × waist interaction term in the model suggested that fat may be distributed differently in different age groups. Recent reports have characterized individuals whose fat is concentrated mostly in the abdomen (android obesity) as more likely to develop many of the health risks associated with obesity than in those with gynoid obesity. Abdominal fat can be further subdivided into visceral and subcutaneous adipose tissue with quantity of visceral fat being a better predictor of some adverse health conditions than subcutaneous fat (Jensen 1997). The estimate of total body adipose tissue provided by DXA did not discriminate between the two types of fat; however, the interaction term suggested that both a measure of body composition and location would be more optimal in evaluating disease risk.

Ultimately, questions about change in body composition and topology over age can be answered definitively only with population-based longitudinal studies that measure within-subject rates of change over the course of increasing age. The need for easy-to-apply cross-sectional measures will remain, however, for clinical and public health screening and epidemiologic studies with large samples. The use of more complex measures of body composition, such as underwater weighing or computed tomography, in large studies has typically been precluded by logistical demands including the number of persons to be evaluated, lack of available facilities and time required to complete the measurements. With better understanding of the relationships between more readily gathered
Aloia, J. F., Vaswani, A., Ma, R. & Flaster, E. (1996) Aging in women—the on the basis of age, sex or ethnicity. Furthermore, an understanding of the influences about the underlying human biology can be made from measures (e.g., circumferences), more valid and reliable inferences about the underlying human biology can be made from those observations. Furthermore, an understanding of the interactions among these measures may help in determining definitions of compartment sizes at specific chronological ages that constitute a health risk. It also may help explain the discrepant observations reported relative to the importance of composition and topology and health risk among populations on the basis of age, sex or ethnicity.

LITERATURE CITED


