ABSTRACT  Our study investigated body composition and body fat distribution in healthy centenarians. Body composition, body fat distribution, and resting metabolic rate (RMR) were studied in 40 adult subjects aged < 50 y, 35 aged subjects > 75 y, and 15 healthy centenarians aged > 100 y. Body composition was determined by bioimpedance analysis, body fat distribution was calculated as waist-hip ratio (WHR), and RMR was calculated by using the Ancero-Poehlman formula. Healthy centenarians had a cognitive impairment and degree of disability greater than aged subjects. Despite such differences, fat-free mass (FFM) and RMR were not different in centenarians compared with aged subjects but were lower than in adult subjects. In contrast, healthy centenarians had a WHR lower than that of aged subjects but not different from that of the adult subjects. After the level of physical activity and degree of disability were adjusted, FFM (44 ± 2.7 and 40 ± 1.1 kg; P < 0.05) and RMR (6757 ± 761 and 5891 ± 723 kJ/24 h; P < 0.05) were significantly higher in healthy centenarians than in aged subjects, respectively. Independent of age, sex, body weight, degree of disability, level of physical activity, and fasting plasma triiodothyronine, there was a strong correlation between RMR and FFM (r = 0.50, P < 0.05) in healthy centenarians. In conclusion, healthy centenarians had a lower FFM and higher body fat content than aged subjects. Level of physical activity and degree of disability seem to be the major determinants for explaining such differences.  Am J Clin Nutr 1995;62:746–50.

KEY WORDS  Healthy centenarians, body composition, body fat distribution, resting metabolic rate

INTRODUCTION  Aging has been associated with significant changes in body composition, body fat distribution, and resting metabolic rate (RMR) (1, 2). In particular, a decline in fat-free mass (FFM) and an increase in body fat occur with increasing age (2). Cross-sectional (3–5) and longitudinal (6) data demonstrate that the greatest loss of FFM in males occurs between ages 41 and 60 y and in females after the age of 60 y. This has an important health implication not only in terms of nutritional status, but also in terms of pharmacokinet (7). The Baltimore Longitudinal Study on Aging (6) showed an ~12% loss of FFM in men aged 75–84 y compared with men aged 25–34 y. Several lines of evidence support the contention that the amount of FFM has functional significance in aging. First, a decline in FFM might be responsible for the age-related decline in RMR (8). Second, the amount of FFM is the main determinant of physical strength in elderly people (9). Third, interventions that improve muscle and FFM improve strength and functional status in elderly people (10). Finally, reduced immune competence accompanies loss of FFM in elderly people as does starvation. In contrast, FFM in elderly people can be increased with exercise (10) or growth hormone therapy (11), thus suggesting that a decline in FFM is not an inevitable accompaniment of advancing age. On the other hand, an increase in body fat distributed centrally has been shown to be associated with altered serum cholesterol indexes, primarily high triacylglycerol and low high-density-lipoprotein (HDL) cholesterol concentrations (12).

Almost all of the nutritional studies of body composition and body fat distribution have been conducted on old (> 65 y) or very old (> 80 y) subjects, whereas none have been conducted in healthy centenarians. The main problem with studying centenarians is their relative low number and their very poor compliance during long or intensive scientific procedures. Bioimpedance analysis (BIA) seems to be a tool sufficiently accurate to assess body composition without the use of very expensive and time-consuming (eg, dual-energy X-ray absorptiometry or underwater weighing) techniques, which can dramatically decrease centenarians' compliance.

The aim of our study was to investigate body composition and body fat distribution in healthy centenarians and to compare such data with those from aged (≥ 75 to < 100 y) and adult (< 50 y) subjects.

SUBJECTS AND METHODS

Subjects  Ninety subjects volunteered for the study. They were divided into three groups: 1) adult subjects (< 50 y old; n = 35); 2) aged subjects (≥ 75 to < 100 y old; n = 40); and 3) centenarians (≥ 100 y old; n = 15). The centenarians repre

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2 This study is part of the Multicenter Italian Study on Centenarians.
3 Address reprint requests to G Paolisso, Servizio di Astanteria Medica, Department of Geriatric Medicine and Metabolic Disease, Piazza Miraglia 2 - I Poli clinico, I-Napoli, Italy.
   Received March 22, 1995.
   Accepted for publication June 19, 1995.
sented a group of carefully selected ambulatory individuals free of major age-related diseases. All subjects were in good health with liver-, kidney-, and thyroid-functions tests within normal range and had no signs of edema or dehydration. No subject used drugs that could affect water-mineral homeostasis. Subjects with a change in body weight of > 2 kg during the preceding year and/or with secondary or Alzheimer dementia were excluded from the study. An oral-glucose-tolerance test (75 g glucose) allowed us to exclude diabetic patients in our population (13). All subjects (as well as relatives of the centenarians) gave informed consent to participate in the study and the study was conducted in accordance with the guidelines of the Helsinki Declaration.

Methods

In aged subjects and centenarians the Mini Mental State Examination (MMSE) (14) and instrumental activity daily living scale (IADL) (15) were used to determine cognitive function and degree of disability. Level of physical activity was assessed by a leisure time physical activities (LTA) table (16).

Weight and height were measured by using a standard beam-balance scale. Percent body fat and FFM were measured by using a four-terminal bioimpedance analyzer (BIA 101/SC; Akern-RJL System, Florence, Italy) (17–19). In particular, all subjects were measured in the supine position after an overnight fast (≥ 12 h) and with an empty bladder. Resistance and reactance were measured with arms and legs abducted. Detector electrodes were placed between the distal prominences of the right radius and ulna and between the right medial and lateral malleoli. Prediction of body fat and FFM by BIA was done with equations validated for a wide age range of elderly people (18). In the present study a strong correlation (r = 0.93, P < 0.001; n = 15) between FFM calculated by BIA and derived by anthropometric measurement was also found. Body mass index (BMI) was calculated as body weight divided by height squared. Waist circumference was measured at the midpoint between the lower rib margin and the iliac crest (normally umbilical level) and hip circumference at the trochanter level. Both circumferences were measured to the nearest 0.5 cm with a plastic tape and the ratio between them provided the waist-hip ratio.

Skinfold-thickness measurements were taken from the triceps and chest with a Harpenden (British Indicators Ltd, London) skinfold caliper. All skinfold-thickness measurements were taken on the right side of the body and were measured to the nearest 1.0 mm. Each skinfold value represents the mean of the three consecutive measurements, and all skinfold-thickness measurements were taken according to the method of Lohman et al (20). Energy intake was recorded from 3-d food diaries. Each subject (or the relatives of the healthy centenarians) was asked to weigh and record intakes of all food and beverages for 3 d.

RMR was calculated by using the Arciero-Poehlman formula (8). This formula has been shown to have a squared correlation coefficient of 0.89 with basal metabolic rate calculated by indirect calorimetry (21). In our study of 30 aged subjects (X ± SD age: 80 ± 4.1 y) and 22 adult subjects (48 ± 3.1 y), RMR was measured by indirect calorimetry (Deltatrac; Datex, Milan, Italy) (7443 ± 448 and 6241 ± 532 kJ/24 h in adult and aged subjects, respectively; P < 0.01) and was calculated by using the Arciero-Poehlman formula (7511 ± 478 and 6338 ± 663 kJ/24 h in adult and aged subjects, respectively; P < 0.01).

There was a strong correlations between RMR measured by indirect calorimetry and RMR calculated by using the Arciero-Poehlman formula (r = 0.85 and 0.87 in adult and aged subjects, respectively). Such a correlation still existed when age was adjusted for (r = 0.35, P < 0.01; n = 52). Fasting plasma glucose, urea, creatinine, albumin, and triacylglycerol concentrations as well as lymphocyte counts were determined by routine laboratory methods. Free triiodothyronine was determined by radioimmunoassay (CV: 4.5 ± 1.1%).

Statistical analyses

Analysis of variance (ANOVA) with Scheffe’s test to calculate differences among the three study groups was used. Analysis of covariance (ANCOVA) was used to adjust FFM and body fat for IADL and LTA scores, and WHR for age, sex, and BMI. Correlations are Pearson product-moment correlations. Partial correlation to study the relation between RMR and FFM independent of body weight, IADL and LTA scores, and fasting plasma triiodothyronine was also performed. Statistical analyses were performed by using the SOLO (BMDP, Cork, Ireland) software package. All values are presented as mean ± SD.

RESULTS

Subject characteristics are given in Table 1. Body weight, height, and FFM significantly declined with advancing age. In contrast, body fat had an opposite trend. A comparison of the two sexes within each group demonstrated that males were heavier than females. In adult and aged subjects, males had a higher FFM and a lower body fat content than females; such differences did not exist for centenarians. Fasting plasma glucose, urea, creatinine, triacylglycerol, and free triiodothyronine concentrations were not different among the subjects. In contrast, MMSE and IADL scores demonstrated a cognitive impairment and a more severe degree of disability in centenarians than in old subjects; however, there were no differences between the two sexes. Because there were no differences in FFM and body fat content between male and female centenarians, these indexes were further analyzed without taking into account sex differences. When the IADL and LTA scores were adjusted for, centenarians had a higher FFM (44 ± 2.7 compared with 40 ± 1.1 kg; P < 0.05) and a lower body fat content (32 ± 4% compared with 38 ± 5%; P < 0.05) than did aged subjects. Centenarians had a significantly lower WHR compared with aged subjects but not compared with adult subjects (Table 1). The WHR was significantly lower in females than in males for both adult and aged subjects; however, the difference was null in centenarians. When adjusted for age and sex, WHR (0.81 ± 0.04) was still lower in healthy centenarians than in aged subjects (0.88 ± 0.03; P < 0.03) and not different from that in adult subjects (0.80 ± 0.05; NS). Body fat distribution was independent of IADL score.

Changes in body weight and fasting plasma albumin concentrations were similar in the three studied groups (Table 2). Aged subjects and centenarians had a lower number of lymphocyte cells and lower skinfold thicknesses, phase angle, and resistance compared with adult subjects (Table 2). In contrast, reactance was significantly increased in aged subjects and
TABLE 1

Characteristics of the study groups

<table>
<thead>
<tr>
<th></th>
<th>&lt; 50 y</th>
<th>≥ 75 y</th>
<th>≥ 100 y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Females</td>
<td>Males</td>
</tr>
<tr>
<td></td>
<td>(n = 18)</td>
<td>(n = 22)</td>
<td>(n = 11)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>43.2 ± 0.4</td>
<td>38.7 ± 2.1</td>
<td>77.6 ± 1.8</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>71.4 ± 0.9</td>
<td>67.1 ± 1.2</td>
<td>70.1 ± 1.4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>178 ± 2.2</td>
<td>175 ± 1.4</td>
<td>177 ± 2.4</td>
</tr>
<tr>
<td>FFM (kg)</td>
<td>56 ± 2.9</td>
<td>51 ± 3.0</td>
<td>48 ± 2.8</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>25 ± 2.0</td>
<td>30 ± 3.3</td>
<td>30 ± 2.4</td>
</tr>
<tr>
<td>Waist-hip ratio</td>
<td>0.83 ± 0.04</td>
<td>0.80 ± 0.02</td>
<td>0.85 ± 0.05</td>
</tr>
<tr>
<td>Fasting plasma glucose (mmol/L)</td>
<td>5.3 ± 0.3</td>
<td>5.2 ± 0.3</td>
<td>5.4 ± 0.3</td>
</tr>
<tr>
<td>Fasting plasma urea (mmol/L)</td>
<td>7.5 ± 0.2</td>
<td>5.0 ± 0.4</td>
<td>9.0 ± 0.8</td>
</tr>
<tr>
<td>Fasting plasma creatinine (mmol/L)</td>
<td>5.3 ± 0.6</td>
<td>5.2 ± 0.7</td>
<td>5.2 ± 0.3</td>
</tr>
<tr>
<td>Fasting plasma triacylglycerol (mmol/L)</td>
<td>1.4 ± 0.5</td>
<td>1.2 ± 0.3</td>
<td>1.2 ± 0.4</td>
</tr>
<tr>
<td>MMSE score</td>
<td>—</td>
<td>—</td>
<td>25 ± 1.1</td>
</tr>
<tr>
<td>IADL score</td>
<td>—</td>
<td>—</td>
<td>9 ± 2.1</td>
</tr>
</tbody>
</table>

1 ± SD. FFM, fat-free mass; FT₃, free triiodothyronine; MMSE, Mini Mental State Examination; IADL, index of activity daily living.
2 Significantly different from males in same age group. P < 0.01.
3 Significantly different from same sex group of subjects aged < 50 y. P < 0.01.
4,5 Significantly different from same sex group of subjects aged ≥ 75 y: 4 P < 0.05, 5 P < 0.001.

In contrast, Silver et al (7), using BIA, demonstrated that fat mass does not appear to increase significantly after the age of 40 y.

To the best of our knowledge, no cross-sectional or longitudinal nutritional data in healthy centenarians have been reported. The results of our study confirm that there is an age-associated effect on body composition and body fat distribution and it is the first report of body composition and body fat distribution in healthy centenarians. In particular, in absolute

TABLE 2

Nutritional assessment of the study groups

<table>
<thead>
<tr>
<th></th>
<th>&lt; 50 y</th>
<th>≥ 75 y</th>
<th>≥ 100 y</th>
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<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Females</td>
<td>Males</td>
</tr>
<tr>
<td></td>
<td>(n = 18)</td>
<td>(n = 22)</td>
<td>(n = 11)</td>
</tr>
<tr>
<td>Change in body weight (%)</td>
<td>2.4 ± 1.8</td>
<td>2.0 ± 1.6</td>
<td>-0.9 ± 0.4</td>
</tr>
<tr>
<td>Fasting plasma albumin (g/L)</td>
<td>4.0 ± 0.6</td>
<td>4.2 ± 0.7</td>
<td>3.8 ± 0.4</td>
</tr>
<tr>
<td>Lymphocytes (cells/mm³)</td>
<td>2775 ± 175</td>
<td>2689 ± 179</td>
<td>2340 ± 178</td>
</tr>
<tr>
<td>Triceps-skinfold thickness (mm)</td>
<td>14 ± 0.7</td>
<td>14 ± 1.4</td>
<td>9 ± 2.8</td>
</tr>
<tr>
<td>Chest-skinfold thickness (mm)</td>
<td>16 ± 4.1</td>
<td>16 ± 6.1</td>
<td>10 ± 2.7</td>
</tr>
<tr>
<td>Resistance (Ω)</td>
<td>591 ± 64</td>
<td>610 ± 79</td>
<td>551 ± 54</td>
</tr>
<tr>
<td>Reactance (Ω)</td>
<td>46 ± 9</td>
<td>51 ± 11</td>
<td>61 ± 10</td>
</tr>
<tr>
<td>Phase angle (°)</td>
<td>6.7 ± 0.4</td>
<td>6.7 ± 0.5</td>
<td>6.0 ± 0.4</td>
</tr>
</tbody>
</table>

1 ± SD. Changes in body weight were calculated as reported in the Methods section. Phase angle was calculated by bioimpedance analysis.
2,3 Significantly different from same sex group of subjects aged < 50 y: 2 P < 0.05, 3 P < 0.001.
TABLE 3
Resting metabolic rate and energy intake in the study groups

<table>
<thead>
<tr>
<th></th>
<th>&lt; 50 y</th>
<th>≥ 75 y</th>
<th>≥ 100 y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males (n = 18)</td>
<td>Females (n = 22)</td>
<td>Males (n = 11)</td>
</tr>
<tr>
<td>Resting metabolic rate (kJ/24 h)</td>
<td>7501 ± 441</td>
<td>7616 ± 491</td>
<td>6318 ± 618(^2)</td>
</tr>
<tr>
<td>Energy intake (kJ/24 h)</td>
<td>8221 ± 770</td>
<td>8337 ± 811</td>
<td>7017 ± 811(^2)</td>
</tr>
</tbody>
</table>

\(^1\) \(\bar{x} \pm SD\).
\(^2\) Significant difference from same sex group of subjects aged < 50 y.
\(^3\) Significantly different from same sex group of subjects aged ≥ 75 y.

terms we demonstrated that healthy centenarians had a lower FFM, greater body fat, and lower RMR than adult and aged subjects. Nevertheless, when the appropriate covariates were taken into account, healthy centenarians had a higher FFM and RMR and a lower WHR than aged subjects.

Our results seem to contrast with other data in aged subjects (1–6). One would expect healthy centenarians to have a further age-dependent decline in FFM and an increase in fat mass. In fact, an age-mediated decline in FFM has been ascribed to disability and overall physical inactivity. On the other hand, intervention such as exercise (10) and growth hormone replacement (11) have demonstrated that a loss of FFM is not an inevitable accompaniment of chronological aging. Indeed, in our study disability and physical activity were measured by internationally validated scales and after adjustment for their score, healthy centenarians had an even higher FFM than aged subjects. Currently, no hormonal data or genetic analyses are available. Nevertheless, an ongoing Italian study of a larger number of centenarians will address such points.

In our study FFM and percent body fat were assessed by BIA, which has several problems associated with it. First, BIA can overestimate FFM in patients who have lost weight. To avoid such problems, dual-energy X-ray absorptiometry and underwater weighing represent better methods to determine body composition (2). Nevertheless, it is impossible to ask centenarians to submit to underwater weighing and very hard to convince them to come to the hospital for dual-energy X-ray absorptiometry. Finally, BIA has been used previously in elderly people only up to 90 y of age. We also used appropriate formulas, which take into account the age and sex of the subjects (18). Furthermore, FFM calculated by BIA and derived by anthropometric measurements was strongly correlated in centenarians.

The WHR is an important anthropometric measure of body fat distribution (23). An increase in WHR is associated with insulin resistance (24) and a more atherogenic plasma lipid pattern (25). The WHR is also strongly influenced by age, sex, and BMI (12). This appears to indicate that as age and BMI increase the WHR also increases. Our results in aged subjects are in agreement with literature data but in healthy centenarians the WHR was lower than in aged subjects. Thus, an age- and BMI-independent effect on WHR in healthy centenarians seems to occur. Such an apparent discrepancy might be explained by differences in nutritional intake, hormonal pattern, and target tissue sensitivity. Finally, a survival effect due to an unknown genetic background cannot be excluded. As far as the survival effect is concerned, it is widely known that a high WHR is indeed associated with a higher mortality due to cardiovascular disease, diabetes, stroke, and cancer. Note that the measurement of body circumferences in very old subjects has some limitations and in our study there was an imbalance between the number of male and female subjects. Only longitudinal studies will provide detailed data to investigate possible difference between male and female centenarians.

The RMR constitutes approximately two-thirds of daily energy expenditure and has been shown to play a major role in the regulation of energy balance (8). With advancing age a decrease in resting and daily energy expenditure, mainly because of a decline in physical activity and changes in body composition, has been shown to occur. Several (26–28) but not all (29, 30) studies have attributed the age-mediated decline in RMR to the loss of FFM. Indeed, the sex ratio in the population studied, level of physical activity, plasma thyroid hormone (total and free triiodothyronine) concentrations, and sympathetic nervous system (SNS) activity are additional factors that should be considered (8, 30). As for SNS activity, it has been demonstrated that elderly people exhibit elevated plasma norepinephrine concentrations and an increased norepinephrine appearance rate compared with younger adults (31, 32). Despite the high level of SNS activity in elderly people, aging is

**FIGURE 1.** Correlation between fat-free mass and resting metabolic rate in centenarians (\(r = 0.73, P < 0.008; n = 15\)).
also characterized by a blunted response to SNS activation that in turn can explain, at least partially, the decreased RMR found in aged subjects (30). At the present time no study has assessed SNS activity in healthy centenarians. One could hypothesize that SNS activity might be a further determinant of the difference in RMR between aged subjects and healthy centenarians. In contrast, thyroid function seems to be less important. In fact, a recent study has demonstrated only a very slight difference in thyroid function between aged and healthy centenarians (33). All these variables can generally explain three-quarters of the variability in RMR whereas one-quarter remains unexplained. In our healthy centenarians RMR (adjusted for age, sex, FFM, levels of physical activity, and fasting plasma free triiodothyronine concentrations) was significantly higher than in aged subjects. As for body composition and body fat distribution, RMR might be upregulated in healthy centenarians by other unknown factors that deserve future investigations.

In our study RMR was calculated by using the Arciero-Poehlman formula (8), which was shown recently to be the most appropriate for such calculation. Indirect calorimetry is surely more accurate in the determination of RMR. Indeed, we only had five centenarians who agreed to undergo indirect calorimetry; therefore, we decided to determine the RMR by using the Arciero-Poehlman formula to make our data more comparable and homogeneous. Our decision was also facilitated by the finding of a strong correlation between RMR calculated from the Arciero-Poehlman formula and RMR determined by indirect calorimetry, independent of age.

In conclusion, our data demonstrate that healthy centenarians have a lower FFM and a higher body fat content than old subjects. The level of physical activity and degree of disability seem to be the major determinants for explaining such differences.

We are deeply indebted to Eric Ravussin and Richard Pratley (NIH, Clinical Diabetes and Nutrition Section, Phoenix, AZ) for their review and suggestions regarding our data interpretation and discussion.

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