Age-Related Changes in Body Fat Distribution in Middle-Aged and Elderly Japanese

Shuichi KOMIYA1), Yasuhiro MURAOKA1), Fu-Sheng ZHANG1) and Takashi MASUDA2)

1) Institute of Health Science, Kyushu University
2) Nakamura Gakuen College

Abstract Total body fat mass was estimated in a group of 65 healthy male and 39 healthy female Japanese aged 40–77 using the D2O dilution method, and by measurement of skinfold thickness at 14 sites. The weights of skin, and subcutaneous and internal adipose tissue were calculated. The women had a higher total adipose tissue weight than the men (p<0.01). Absolute subcutaneous adipose tissue weight in women was about double that in men. However, absolute internal adipose tissue weight and internal adipose tissue weight as a percentage of body weight showed no significant sex difference.

The relationship of total and subcutaneous adipose tissue weight with age showed a correlation of r = -0.283 (p <0.05) and r = -0.367 (p<0.01), respectively, for men and r = -0.329 (p<0.05) and r = -0.428 (p<0.01), respectively, for women. The correlation of internal adipose tissue weight with age was not significant, but the internal adipose tissue weight/total adipose tissue weight ratio increased steadily with age in both sexes.

Key Words Age change, Body fat, D2O dilution, Subcutaneous adipose tissue, Internal adipose tissue

Introduction

Biologic aging is a process involving changes that influence the body’s total functional capacity. Body composition is an important aspect of health related to nutritional status. Numerous studies have indicated that biologic aging is associated with a number of adverse changes in body composition. With advancing age, the body’s fat-free tissue weight decreases (NOVAK, 1972; FORBES, 1976) whereas fat tissue weight increases (NOVAK, 1972; DURNIN and WOMERSLEY, 1974; NOPPA et al., 1979).

There have been two different approaches to studying the composition of the human body – direct and indirect. The best data on human body composition come from cadaver dissection. However, one disadvantage of this direct approach is the difficulty involved in collection of materials, resulting in a small sample size.

Most body composition methods are based upon a model in which the body consists of two
chemically distinct compartments, fat mass and 
fat-free mass. The pioneering work of BEHNKE 
et al. (1942) and BROZEK (KEYS and BROZEK, 
1953) resulted in the establishment of densito-
metry as the criterion by which all other indirect 
methods were evaluated as a basis for body 
composition studies. On the other hand, the most 
common currently used technique for determina-
tion of body composition is the use of skinfold 
calipers to predict body fat composition. How-
ever, attempts to describe the theory and practice 
of individual indirect methods have been limited.

The main problem in evaluating the effect of 
age on body composition involves the assump-
tion underlying the various body composition 
techniques. The density of human bone declines 
with age (TROTTER et al., 1960); so too does the 
ratio of body potassium to total body water 
(BRUCE et al., 1980; COHN et al., 1980; PIERSON 
et al., 1982). The result is that the density of lean 
body mass is probably lower in elderly than in 
young adults, and the potassium content also 
smaller. Skinfolds are more easily compressible 
in the elderly, and therefore estimates of body 
fat by anthropometry tend to be low.

Although the total body water method is not 
affected by age, the ratio of extracellular to 
intracellular water does change (FORBES, 1987). 
The findings that water is not present in stored 
triglyceride and that water accounts for a rela-
tively fixed fraction (73.2%) of the fat-free mass 
(PACE and RATHBUN, 1945) have stimulated the 
determination of total body water as an index of 
age-related changes in human body composition.

On the other hand, distribution of fat in 
certain body regions is known to be often 
associated with hypertension and metabolic 
disorders, such as hyperlipidemia and glucose 
intolerance. Computerized tomography (CT) and 
magnetic resonance imaging (MRI) are modern 
techniques applied recently for determination of 
regional body composition. However, there have 
been no studies of age-related changes in gross 
weight of subcutaneous adipose tissue and 
internal adipose tissue in Japanese subjects.

The purpose of this study was to provide data 
on age-related changes in body fat distribution 
in adult Japanese.

Subjects and Methods

Sixty-five men and 39 women served as 
volunteers. All participants were healthy, with 
documentation from their personal physicians 
certifying no known major medical disorders. 
The purpose of the investigation was fully ex-
plained to each participant, and all gave written 
informed consent before commencing the study. 
This population included subjects with a wide 
range of ages, heights, weights and body com-
positions. Their physical characteristics are 
summarized in Table 1.

After an overnight fast, height (cm) and body 
weight (kg) were measured with the subjects 
barefooted and lightly clothed. Each subject 
emptied the bladder, then drank 1 g/kg body 
weight of 99.75% D2O (Wako Pure Chemical 
Industries, Ltd.) mixed with drinking water. 
After a 1–3 h equilibration period, urine 
samples were collected. The urine samples were 
then placed in a distillation apparatus, and HOD 
concentrations were determined by infrared 
absorption (THORNTON and CONDON, 1950; 
TRENNER et al., 1953; TURNER et al., 1960; 
JONES and MACKENZIE, 1960; STANSELL and 
MOJICA, 1968; KOMIYA et al., 1981). The error 
of deuterium concentration determined by this 
method is 2.55% (KOMIYA et al., 1981). Total 
body water (TBW) was calculated from the dose 
administered and the observed deuterium con-
centration in the urine samples. TBW was then 
used to estimate fat-free mass employing the 
equation developed by PACE and RATHBUN 
(1945). Total adipose tissue weight (TATW) 
determined by the D2O dilution method was
Table 1. Physical characteristics of the subjects

|                         | Male                                      | Female                                   |
|-------------------------|-------------------------------------------|------------------------------------------|
|                         | Middle-Aged 1)                           | Middle-Aged 2)                           | Total (N=65)                            | Middle-Aged 1)                           | Middle-Aged 2)                           | Total (N=39)                            |
|                         | n = 42                                   | n = 23                                   | Mean ± S.D.                             | n = 25                                   | n = 14                                   | Mean ± S.D.                             |
| Age, yr                 | 47 ± 4.6                                 | 67 ± 4.6                                 | 54 ± 10.7                               | 49 ± 5.9                                 | 65 ± 4.2                                 | 54 ± 9.6                               |
| Height, cm              | 164.7 ± 6.7                              | 163.2 ± 6.6                              | 164.2 ± 6.6                             | 152.6 ± 4.6                              | 151.7 ± 4.9                              | 152.3 ± 4.7                             |
| Body Weight, kg         | 66.47 ± 12.092                           | 56.66 ± 7.495                            | 63.46 ± 11.830                          | 59.33 ± 7.701                            | 54.25 ± 12.101                           | 57.63 ± 9.702                           |
| Body Mass Index, kg/m²  | 24.4 ± 3.20                              | 21.3 ± 2.33                              | 23.4 ± 3.32                             | 25.5 ± 3.16                              | 23.4 ± 4.18                              | 24.7 ± 3.66                             |
| Body Surface Area, cm²  | 16927 ± 1718.4                           | 15652 ± 1221.2                           | 16460 ± 1673.5                          | 15259 ± 1015.9                           | 14549 ± 1647.3                           | 15004 ± 1303.6                          |
| Total Body Water, f     | 34.7 ± 5.36                              | 30.6 ± 3.64                              | 33.2 ± 3.59                             | 27.3 ± 2.66                              | 25.0 ± 4.59                              | 26.5 ± 3.59                             |
| Average Skinfold, mm    | 15.8 ± 5.02                              | 11.5 ± 2.79                              | 14.3 ± 4.81                             | 22.0 ± 4.71                              | 18.5 ± 5.46                              | 20.8 ± 5.21                             |

1) Aged 60 and below
2) Aged 61 and above

Calculated as:

\[ \text{TATW, kg} = \text{body weight, kg} - (\text{TWB,} / 0.732) \]

The skinfold procedure for determining subcutaneous fat involved 14 skinfold sites on the right side of the body: cheek, chin, chest I (diagonal fold just superior and lateral to the nipple), chest II (vertical fold on the midaxillary line at the level of the xiphoid process), abdomen, suprailiac, triceps, scapula, back I (vertical fold just adjacent to and level with the vertebra prominens), back II (vertical fold just adjacent to the spinal column and level with and just below the arcus costalis), thigh I (vertical fold on the anterior aspect of the thigh midway between the superior aspect of the patella and anterior superior iliac spine), thigh II (vertical fold on the posterior aspect of the thigh I), knee, calf (vertical fold on the posterior aspect of the calf at the level of maximal circumference, subject seated with lower leg dangling). The skinfold was grasped firmly between the thumb and index finger, and the Eiken caliper was placed perpendicular to the fold approximately 1 cm from the finger. The dial was read to the nearest 0.5 mm approximately two or three seconds after releasing the grip. The average value for the 14 skinfold sites was calculated and applied to the equation for determination of subcutaneous adipose tissue weight (SATW). Body surface area was calculated using the equation of FUJIMOTO et al. (1968) and skin weight (SW) was calculated from body weight using the SATAKE and OZAKI equation (1991). The density of fat was taken as 0.900 g/cm³ (FIDANZA et al., 1953).

\[ \text{SATW, g} = \left( \frac{\text{average of 14 skinfolds, cm}}{2} \right) \times \text{body surface area, cm}^2 \times 0.900, \text{g/cm}^3 - \text{SW, g} \]

Internal adipose tissue weight (IATW) was calculated as the difference between TATW and SATW.

Results

Means and standard deviations for SW, TATW, SATW, IATW, and their proportion relative to body weight (BW) and TATW for the Japanese subjects are given in Table 2. SW was slightly higher in middle-aged men than in middle-aged women (p<0.05). However, SW/BW for middle-aged women was slightly higher than for middle-aged men (p<0.05). On average, the elderly women had a higher TATW than the elderly men (p<0.01). SATW in women was about twice that in men. Only IATW and IATW/BW showed no significant sex difference (p>0.05). However, IATW/TATW was higher in men than in women. The male/female ratio for SATW/TATW and IATW/TATW were 0.78 and 1.22 in all subjects, respectively. SATW/TATW was higher in middle-aged men and women than in elderly men and women.
Table 2. Means and standard deviations of gross tissue weight and their percentages for the subjects

|               | Male                  | Female                | Sex Difference |                  |
|---------------|-----------------------|-----------------------|----------------|-----------------|
|               | Middle-Aged\(^1\)    | Elderly\(^2\)         | Total          | Middle-Aged\(^1\) | Elderly\(^2\) | Total |                  |
|               | n = 42                | n = 23                | N = 65         | n = 25          | n = 14          | N = 39 |                  |
| Age           | Mean ± S.D.            | Mean ± S.D.            | Mean ± S.D.    | Mean ± S.D.     | Mean ± S.D.     | Mean ± S.D. |                  |
| SW, kg        | 3.53 ± 0.527          | 3.11 ± 0.326          | 3.40 ± 0.515   | 3.23 ± 0.335    | 3.00 ± 0.527    | 3.15 ± 0.422 | *                |
| TATW, kg      | 19.73 ± 6.200         | 14.85 ± 4.378         | 18.00 ± 6.060  | 22.17 ± 4.935   | 20.02 ± 6.512   | 21.40 ± 5.566 | **               |
| SATW, kg      | 8.81 ± 4.462          | 5.07 ± 2.002          | 7.46 ± 4.160   | 12.04 ± 3.778   | 9.43 ± 4.364    | 11.10 ± 4.140 | **               |
| IATW, kg      | 10.91 ± 3.060         | 9.79 ± 3.181          | 10.54 ± 3.193  | 10.12 ± 2.203   | 10.60 ± 2.794   | 10.30 ± 2.406 |                  |
| SW/BW, %      | 5.3 ± 0.17            | 5.5 ± 0.16            | 5.4 ± 0.19     | 5.4 ± 0.14      | 5.6 ± 0.25      | 5.5 ± 0.19     | *                |
| TATW/BW, %    | 28.9 ± 5.26           | 25.7 ± 5.54           | 27.8 ± 5.54    | 36.8 ± 4.37     | 36.2 ± 5.07     | 36.6 ± 4.58    | **               |
| SATW/BW, %    | 12.7 ± 4.90           | 8.8 ± 3.03            | 11.1 ± 4.51    | 19.8 ± 4.11     | 16.6 ± 5.03     | 18.7 ± 4.67    | ***              |
| IATW/BW, %    | 16.7 ± 5.43           | 17.1 ± 4.23           | 16.7 ± 4.49    | 17.0 ± 3.03     | 19.6 ± 3.01     | 17.9 ± 3.23    | **               |
| SATW/TATW, %  | 42.8 ± 12.91          | 33.7 ± 8.76           | 39.4 ± 12.12   | 53.5 ± 7.95     | 45.2 ± 9.98     | 50.5 ± 9.51    | ***              |
| IATW/TATW, %  | 57.2 ± 12.91          | 66.3 ± 8.76           | 60.5 ± 12.39   | 46.5 ± 7.95     | 54.8 ± 9.98     | 49.5 ± 9.51    | **               |

1) Aged 60 and below  
2) Aged 61 and above  
SW; skin weight, TATW; total adipose tissue weight, SATW; subcutaneous adipose tissue weight, IATW; internal adipose tissue weight, BW; body weight  
*; p<0.05, **; p<0.01, ***; p<0.001
On the other hand, IATW/TATW was higher in elderly than in middle-aged in both sexes \((p<0.01)\).

Fig. 1 shows the relationship between SATW or IATW and TATW. Correlation coefficients of SATW and IATW with TATW were 0.869 and 0.766, respectively, for men, and 0.918 and 0.733, respectively, for women. All the correlation coefficients were significant \((p<0.001)\). The F-test revealed no significant sex difference between the slopes of these regression lines.

Fig. 2 shows the calculated regression lines for TATW, SATW and IATW as a function of age for men and women. The correlation coefficient between TATW or SATW and age was \(-0.283\) and \(-0.367\), respectively, for men, and \(-0.329\) and \(-0.428\), respectively, for women. All correlation coefficients were significant. However, the correlation coefficient of IATW with age was not significant \((p>0.05)\) in both sexes.

Fig. 3 shows the relationship between the SATW/TATW or IATW/TATW and age. The trend for SATW/TATW was clearly downward during this period. However, IATW/TATW increased steadily with age.

**Fig. 1.** Subcutaneous (SATW) and internal adipose tissue weight (IATW) as a function of total adipose tissue weight (TATW).
Discussion

With advancing age, changes in body composition occur; fat-free mass decreases (NOVAK, 1972; FORBES, 1976) and fat mass increases (NOVAK, 1972; DURNIN and WOMERSLEY, 1974; NOPPA et al., 1979). However, there are very few data on body composition during adult
Body Fat Distribution in Adult Japanese

Fig. 3. Subcutaneous and internal adipose tissue weight as a percentage of total adipose tissue weight against age.

life in Japanese. In addition, there have been no studies of age-related changes in body fat distribution, which is associated with ethnicity and illness (MUELLER et al., 1982, 1984). Body fat distribution refers to subcutaneous adipose tissue and internal adipose tissue. Age-related change in body fat distribution is an important aspect of health related to nutritional status.

SATAKE and OZAKI (1991), using direct methods, estimated that SATW was 3.18 kg (6.3% of BW) in older Japanese men and 5.82 kg (12.3% of BW) in older Japanese women. On the other hand, using skinfold measurements obtained from 121 men and 93 women, aged 18 to 23 years, HATTORI et al. (1991) calculated a mean SATW value of 4.1 kg for younger Japanese men and 6.9 kg for younger Japanese women. In the present study, mean SATW was 8.81 kg (12.7%) in middle-aged men, 5.07 kg (8.8%) in elderly men and 12.04 kg (19.8%) in middle-aged women, 9.43 kg (16.6%) in elderly women, respectively. BAKER (1969) and DAVIES
(1986) estimated that the proportion of fat in adipose tissue was 80%. Therefore, the fat content of SATW measured in this study was estimated to be about 4–7 kg in men and about 8–10 kg in women, which are higher values than those in other reports. In the SATAKE and OZAKI (1991) series, mean age was higher, and mean body weight lower than in this study. On the other hand, mean age in the HATTORI et al. (1991) series was lower than in this study. Thus the difference in the results may have been due to the differences between the subjects.

LOHMAN (1981), using various techniques, estimated that the amount of subcutaneous fat as a percentage of total body fat ranged from 20% to 70% depending on factors such as age, sex, degree of obesity, and method of measurement. The corresponding percentages in this study lie roughly within the range indicated by LOHMAN (1981).

Sex hormones are known to affect the distribution of body fat (EVANS et al., 1983). Indeed, the sex difference in SATW (male/female ratio = 0.73 in middle-aged) is greater than that in TATW (male/female ratio = 0.89 in middle-aged). However, mean IATW and IATW/BW showed no significant sex differences.

On the other hand, IATW/TATW increased steadily with age. It would be of interest to determine whether this aging trend could be modified by nutrition or physical activity. POND (1978) has suggested two factors favoring a centralized fat distribution: mechanical efficiency and changes in sexual signalling over the life cycle. IATW/TATW variation with advancing age may be related to physical activity and sex hormones. Thus a decrease of physical activity and female sex hormone may promote relative accumulation of internal adipose tissue in the elderly.

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Body Fat Distribution in Adult Japanese

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