Use of B-mode Ultrasound for Visceral Fat Mass Evaluation: Comparisons with Magnetic Resonance Imaging

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Abstract. The validity of the visceral fat evaluation based on B-mode ultrasonography was tested on 30 healthy young women (mean age 19.6 years). The mass of visceral fat (VFM) was estimated by subtracting the subcutaneous fat mass (SFM) from the total body fat mass. The SFM was calculated as the sum of segmental subcutaneous fat mass determined from the surface area and mean thickness of adipose tissue in six body segments (face and neck, upper arm, forearm, thigh, lower leg, and trunk). Reproducibility of the determination of VFM by the repeated measures of SFM and total fat mass was sufficiently high with the difference of 5.0%. Serial cross-sectional areas of visceral adipose tissue (VATarea) were measured by magnetic resonance imaging (MRI) at three different positions of the trunk (at umbilicus and at 3.5 cm upper and lower positions). The VFM correlated significantly to each VATarea (r = 0.75 to r = 0.78, P < 0.01). The present findings suggest that the VFM can be determined with the use of B-mode ultrasonography for the clinical assessment and field surveys. (Appl Human Sci, 14(3): 133-139, 1995)

Keywords: body fat distribution, subcutaneous fat, adipose tissue area

Introduction

Numerous attempts have recently been made to evaluate body fat or adipose tissue in terms of subcutaneous and visceral one because it has been shown that body fat distributions rather than the total body fat mass itself are related to the onset of diabetes, hypertension, dyslipidemia, and cardiovascular diseases (Bjorntorp, 1988; Despres et al., 1990; Kissebah and Peiris, 1989). Two methods of evaluating visceral fat mass have so far been proposed. One is based on the calculation of visceral adipose tissue (AT) area or AT volume from the cross-sectional images of the trunk by some scanning techniques (Ashwell et al., 1985; Borkan et al., 1982; Fowler et al., 1991; Kvist et al., 1988; Ross et al., 1992; Seidell et al., 1987 and 1990). The other calculates subcutaneous fat mass by using calipers or ultrasonography and subtract it from the total body fat mass determined by hydrodensitometry (Brown and Jones, 1977; Davies et al., 1986; Hattori et al., 1991; Skorjil et al., 1953). The former method gives estimation of visceral fat mass with good accuracy, but the necessity of such special devices as computed tomography or magnetic resonance imaging (MRI) prevents clinical use or field surveys for preventive medicine. In such a case the latter method has been used.

Ultrasonography, which has recently been greatly developed and scanning devices have become much smaller in size with high accuracy (Kawakami et al., 1993). It has been used for measurement of thickness of tissues like AT or muscles. Davies et al. (1986) reported that using ultrasonography and measuring subcutaneous AT thickness, subcutaneous and visceral fat mass could be estimated. If visceral fat mass could be estimated by ultrasonography, clinical application or field assessment of visceral fatness would be much easier and less expensive, without using expensive and bulky apparatuses (MRI, CT, etc.) which limit their use to purely laboratory studies. Unfortunately however, the validity of the ultrasound methodology has not been proven yet. The objective of the present study is to compare the above two methods of evaluating visceral fat mass to investigate the validity of visceral fat mass determination based on ultrasonography.

Subjects and Methods

Subjects

The subjects for this study were 30 Japanese females aged between 18 to 25 years old. They were all volunteers whose body composition was within the normal range of the Japanese. They suffered from no disease
and endocrine disorders. Written informed consent was obtained from each subject prior to participation. Physical characteristics of the subjects are shown in Table 1.

**Total fat mass determination based on hydrodensitometry**

The body density (BD) was calculated from simultaneous measurements of underwater weight and residual lung volumes (Abe et al., 1994). Body weight in water was measured by using a force electric-plate, equipped with a chair. The water temperature was maintained at 37 ± 1°C. Residual lung volume was measured by oxygen dilution technique (Rahn et al., 1949). The percentage of body fat (%Fat) was calculated from BD using the Siri equation (1961) and the total body fat mass (TFM) was determined.

**Subcutaneous fat mass determination based on ultrasonography**

Ultrasonographic evaluation of subcutaneous AT (including skin) was performed by using a real-time linear electronic scanner (SSD-500, Aloka Co., Ltd., Tokyo). The scanning head was coated with the water-soluble transmission gel which provided acoustic contact without depression of the skin surface and was placed perpendicular to the tissue interface under the marked site. Distortion of tissues due to excess compression was eliminated by observing that no movement of tissues occurred in a real-time ultrasonic image. Subcutaneous AT was measured directly from the screen with the use of electronic calipers positioned at the skin and AT-muscle interfaces (Abe et al., 1994). Dermis thickness was excluded according to Tan et al. (1982). Reliability of image reconstruction and distance measurements was confirmed elsewhere by comparing the ultrasonic and manual measurements of tissue thickness, using human cadavers (Kawakami et al., 1993).

Subcutaneous fat mass (SFM) was calculated from the AT thickness measurements using an equation derived by Davies et al. (1986), i.e.,

\[
\text{Mean thickness of adipose tissue} \times \frac{\text{Density of fat}}{\text{Density of adipose tissue}} \times \frac{\text{Proportion of fat in adipose tissue}}{\text{Proportion of adipose tissue}} \times (m^3) = \text{SFM (kg)}
\]

Total mass of subcutaneous fat was calculated as the sum of subcutaneous fat mass of each body segment which was estimated from the surface areas and mean thicknesses of subcutaneous adipose tissue (AT) layers at face and neck, upper arm, forearm, thigh, lower leg, and trunk (Hattori et al., 1991). Following Shintani (1931), the whole body surface was sectioned into nine areas. Because subcutaneous fat was scarce or difficult to measure on the scalp, hand, and foot segments, these segments were not included in calculating SFM. Several sites were selected in each segment (except forearm) covering anterior and posterior areas and the average AT thicknesses at those sites were considered as the representative AT thickness of each segment. As for the trunk, due to large variation of AT thicknesses, six sites were selected for measurement. Before measurement, the sites were precisely located and marked with a surgical pen. The measurements were made on the right side of each subject in standing position. Fifteen sites for measurement out of six body segments and their anatomical landmarks for the sites were as follows:

1) Forehead; At a distance 2 cm above the eyebrows. 2) Nuchal; On the posterior surface of the neck at the level of the just below the laryngeal prominence. 3) Forearm; On the lateral surface 30% proximal between the styloid process and the head of the radius. 4) Biceps and 5) Triceps; On the anterior and posterior surface, 60% distal between the lateral epicondyle of the humerus and the acromion process of the scapula. 6) Anterior chest; At a distance 2 cm below the mid-point of the clavicle. 7) Supra-iliac; In the mid-axillary line immediately above the iliac crest. 8) Mid-axillary; In the mid-axillary line at the level of the xiphoid-sternal junction. 9) Abdomen; At a distance 2-3 cm to the right of the umbilicus. 10) Subscapula; At a distance 5 cm directly below the inferior angle of the scapula. 11) Sub-sternum; Just lateral of the xiphoid process. 12) Quadriceps and 13) Hamstrings; On the anterior surface, mid-way between the lateral condyle of the femur and from the greater trochanter. 14) Gastrocnemius and 15) Tibialis anterior; On the anterior and posterior surface, 30% proximal between the lateral malleolus of the fibula and the lateral condyle of the tibia.

Body surface area was calculated using the equation of Nakamura (1959): S = W^{0.426} \times H^{0.725} \times 70.98. The density of fat was taken as 900 kg/m³ (Fidanza et al., 1953). The proportion of fat in adipose tissue was considered to be 0.8 according to Baker (1969) and Garrow (1978).

**Visceral fat mass estimation based on TFM and SFM**

Visceral fat mass (VFM) was calculated as the difference between TFM and subcutaneous fat mass (SFM). The reliability of TFM, SFM and VFM measurements was repeatedly tested on 12 female subjects out of 30 subjects. Duplicate measures were taken separately with an interval of approximately seven days.

**Adipose tissue area measurement based on MRI**

Transverse MR images were obtained with a whole-body MRI scanner (Magnetom H15, Siemens Co. Ltd.) with a 1.5-T magnetic field using a body coil with a diameter of 55-cm. Three images were obtained at 3-cm interval with the center image at the umbilicus, one scan above and the other below this level. Each subject rested in a supine position. We used a 128 x 128 matrix, a slice thickness of 5 mm, a field of view of 500-mm/1.5 (333-
mm), giving a 6.78-mm² pixel area. Magnitude images were obtained from a spin-echo sequence; repetition time was 150-ms, and echo time was 15-ms for all acquisition. Calculation of AT areas were performed and interpreted as described previously (Ross et al., 1992). The areas of AT regions (subcutaneous and visceral) in each slice were computed automatically by summing AT pixels, multiplied by the pixel surface area. The threshold selected for AT was based on the analysis of a sample of typical images and the respective gray level histograms. Results demonstrated that the optimal threshold for AT was 160-170: pixels above this level were considered as representing AT. The threshold of AT was confirmed and corrected by obtaining MR images of two glass bottles 14.5 cm long and 4.0 cm wide filled to its capacity with peanut oil, each placed on either side of the subject. Reliability of AT area measurement by the present methodology has been confirmed elsewhere (Ross et al., 1992). Reproducibility of this method was checked with 5 of the subjects by performing duplicate measurements of AT areas with deviations of less than 7%.

**Anthropometric Measurements**

Height was recorded to the nearest 0.1 cm and body weight to the nearest 0.1 kg of subjects clad only in swimsuit. Body mass index (BMI) was calculated as weight divided by height squared (kg/m²). Circumferences were measured with a plastic tape measure at the following levels: 1) waist circumference at midway between the lower rib margin and the iliac crest, 2) widest hip circumference, and 3) mid-thigh circumference. The waist-to-hip circumference ratio (WHR) was calculated as waist circumference divided by hip circumference. The waist-to-thigh ratio (WTR) was calculated in a similar way.

**Statistical Analysis**

Results are expressed as means ± SD. Linear regression analysis was used to assess the simple relationship between variables. Two-sided P values were considered statistically significant set at P<0.05.

### Results

**Reliability of TFM, SFM and VFM Measurements**

The mean differences between test 1 and 2 for TFM, SFM and for VFM were calculated as 0.4%, 2.5% and 5.0%, respectively (Table 2). Therefore, these results were considered to show the accuracy and reliability of measurements and acceptability of the present methodology for use in this investigation.

**TFM, SFM and VFM, and their relations to anthropometric variables**

Descriptive characteristics of the subjects are shown in Table 1. Differences in age and anthropometric variables were small. Total body fat mass (TFM) was 13.9 kg (percent fat 25.7%) with average of SFM of 10.3kg and VFM of 3.6kg. SFM and VFM accounted for 74.1% and 25.9% of TFM, respectively. Ultrasonic inspection demonstrated that 36.6% of SFM accumulated in the trunk and 38.2% in the thigh, both reaching 74.8% of total SFM. Statistically significant correlations were observed between SFM and body weight (r=0.79; P<0.01), SFM and BMI (r=0.85; P<0.01). For VFM, similar but weaker relationships were found for body weight (r=0.43; P<0.05) or BMI (r=0.38; P<0.05). The VFM further correlated with waist circumference (r=0.49; P<0.01) and WHR (r=0.36; P<0.05).

**Subcutaneous and visceral AT areas by MRI**

Among the three positions where images were obtained, the largest subcutaneous and visceral AT areas were observed at the lowest one, i.e. 3.5 cm below umbilicus (total AT area; 204.2±70.2 cm², subcutaneous AT area; 161.1±65.9 cm², visceral AT area; 43.2±12.5 cm²). Smaller inter-individual difference was found compared with the previous results (Ashwell et al., 1985; Ross et al., 1992). Visceral AT area accounted for 21.23% of the total AT area at three positions.

**Relationship between SFM, VFM and MRI-measured AT areas**

<table>
<thead>
<tr>
<th>Table 1 Descriptive characteristics of 30 female subjects</th>
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<tbody>
<tr>
<td>Variable</td>
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<tr>
<td>---------------------</td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Height (cm)</td>
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<tr>
<td>Weight (kg)</td>
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<tr>
<td>Body mass index (kg/m²)</td>
</tr>
<tr>
<td>Waist to hip ratio</td>
</tr>
<tr>
<td>Waist to thigh ratio</td>
</tr>
<tr>
<td>Percent fat (%)</td>
</tr>
<tr>
<td>Total body fat mass (kg)</td>
</tr>
<tr>
<td>Visceral fat mass (kg)</td>
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<tr>
<td>Subcutaneous fat mass (kg)</td>
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</tbody>
</table>
Table 2 Test-retest reliability of subcutaneous and visceral fat mass estimation

<table>
<thead>
<tr>
<th></th>
<th>Test 1</th>
<th>Test 2</th>
<th>Δ%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcutaneous Fat Mass (kg)</td>
<td>9.9(1.9)</td>
<td>9.6(1.7)</td>
<td>2.5</td>
</tr>
<tr>
<td>Visceral Fat Mass (kg)</td>
<td>3.3(1.1)</td>
<td>3.6(1.2)</td>
<td>-5.0</td>
</tr>
</tbody>
</table>

Values are mean (SD) for 12 young women. Δ%, (Test 1−Test 2)/Test 1 x 100

Table 3 Correlation matrix between MRI-measured AT areas and each fat mass

<table>
<thead>
<tr>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Umbilicus Sub AT area</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) Umbilicus Vis AT area</td>
<td>0.32</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) Umbilicus Total AT area</td>
<td>0.98**</td>
<td>0.50*</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4) Subcutaneous Fat Mass</td>
<td>0.90**</td>
<td>0.28</td>
<td>0.88**</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5) Visceral Fat Mass</td>
<td>0.26</td>
<td>0.75**</td>
<td>0.40*</td>
<td>0.20</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>6) Total Fat Mass</td>
<td>0.85**</td>
<td>0.51*</td>
<td>0.88**</td>
<td>0.92**</td>
<td>0.55*</td>
<td>–</td>
</tr>
</tbody>
</table>

Correlations are significant at* p<0.05, **p<0.01.

Table 3 depicts the relationship between AT areas (subcutaneous, visceral and total) and estimated fat mass (TFM, SFM and VFM) based on ultrasonic measurements. Strong positive correlations were observed between total AT area and TFM (r=0.88) and SFM (r=0.88). Subcutaneous AT area highly correlated with SFM (r=0.90) and TFM (r=0.85). However, no significant relations were noted between VFM and SFM or subcutaneous AT area by MRI. Correlation coefficients between VFM and visceral AT areas at three positions are listed in Table 4. Significant correlations were noted with r ranging from 0.75 (Fig.1) to 0.78 (P<0.01).

Discussion

To the best of our knowledge, this is the first study in which validity of VFM determination based on ultrasonic measurements was tested by comparison with directly determined visceral AT area by MRI. Attempts have recently been made to assess visceral AT area and AT volume using MRI. This methodology is superior to others in that visceral AT can be visualized and accurately measured, but it is not suitable for field tests on a large number of subjects. Moreover, it is not realistic to use MRI for visceral AT measurement on healthy people except for clinical research work. On the other hand, the present method which was based on ultrasonography can be easily applied to many healthy individuals. The reproducibility of TFM, SFM and VFM determination based on hydrodensitometric and ultrasonic measurements was sufficiently high with deviations in duplicate measures less than 5.0% and especially SFM gave higher reliability. This was probably due to the high accuracy of subcutaneous AT thickness measurement by B-mode ultrasound (Kawakami et al., 1993). These deviations were similar to those found in previous report, in total/regional AT volume measurement by MRI (Ross et al., 1992).

Seidell et al. (1990) compared AT area measurements using computed tomography (CT) and MRI and proved the potential of MRI from the “gold standard” validation by carcass dissection. They reported that the correlation coefficients for the subcutaneous and visceral fat between MRI and CT were as high as r=0.964 and r=0.893, respectively. Other studies comparing MRI images and direct anatomy have shown similar results (Fowler et al., 1992). However, it has been reported (Ross et al., 1991 and 1992) that MRI pixel intensity values for a given tissue may not be consistent from slice to slice or between individuals, making it difficult to identify specific tissues and to measure their cross-sectional areas. In this study, according to the previous reports (Ross et al., 1992), serial scans were performed by MRI with standards of known chemical composition imaged together, and pixel intensity of AT in each image was corrected for consistency based on the intensity of the images of the standards to reduce errors in image processing. Artifacts of images as reported by Ross et al. (1992) were not observed.

Mean values of TFM, SFM and VFM were similar to those of previous reports whose subjects were almost the same age (Davies et al., 1986). Hattori et al. (1991) measured AT thickness by skinfold calipers and TFM by underwater weighing, and calculated VFM. They reported a higher proportion of VFM to total fat mass than that of the present study. In the case of skinfold method, half of the skinfold measurement has been used as AT thickness, but this is smaller than that by ultrasonic measurement (Kuczmarski et al., 1987; Weits et al., 1986). Since AT thickness measures by ultrasound have been taken from direct dissection of the tissue (Kawakami et al., 1993), SFM calculation by skinfold might underestimate the real value. Thus VFM, which is defined as the difference between TFM and SFM, would be greater if calipers were used instead of ultrasound. The discrepancy would be greater especially in obese
subjects. Ultrasonic method would therefore be superior to caliper method in assessing SFM more accurately with its reliability in AT thickness measurement.

Brokan et al. (1982) studied the relationship between total, subcutaneous, visceral AT areas at abdomen and body fat mass, the former obtained by CT method and the latter by 4K counting. Total fat correlated with total and subcutaneous AT areas (r = 0.70 and 0.74 respectively), but correlation coefficient between total fat and visceral AT area was low (r = 0.33). Similarly, several MRI studies (Ross et al., 1992) showed that total AT volume related strongly with subcutaneous AT area at abdomen but only weakly with visceral AT area, which coincides with the present findings. In the study using MRI (Ross et al., 1992) a strong positive correlation between visceral AT volume and visceral AT area in a single slice was observed (r = 0.89 - 0.97). Furthermore, Armellini et al. (1994) studied the relationships between ultrasound intra-abdominal thickness (ultrasound measurement of distance between abdominal muscle and aorta) and visceral adipose tissue area by computed tomography (CT). The reported correlation of r = 0.712 for young and middle-aged women. In the present study, VFM estimated by ultrasound significantly correlated with MRI-measured visceral AT area (r = 0.75 - 0.78, P < 0.01). This suggests that VFM estimation reflects actual visceral AT mass, but the correlations were lower compared to the previous reports (Ross et al., 1992 and 1993) which is so far the only attempt to measure whole body AT volume by MRI. Considering that visceral AT increases with age and that Ross et al. (1992) had subjects whose age and physical characteristics varied greatly, the lower correlations might be attributed to rather small variations in age and physical dimensions of the young women who served as subjects in this study. Ross et al. (1992) employed subjects whose visceral fat area ranged from 26.6 - 162.1 cm², which is a six-fold difference, while in the present study the visceral fat area ranged only from 19.1 - 69.9 cm² at the umbilicus level. Further studies on the applicability of the present procedure on a larger number of subjects will be necessary before the methodology can be used for the VFM evaluation.

Our results confirm the findings of Ashwell et al. (1985) that waist circumference ratios were related more strongly to intra-abdominal than to subcutaneous fat. However, the present correlation coefficient between VFM and WHR was significant (r = 0.36) but low, with variation in WHR explaining that of VFM by only 13%. Thus, the WHR might as well be used in an epidemiological study to assess the degree of visceral-fatness on a very large number of subjects, but should not be used for accurate evaluation of VFM (Van der Kooy et al., 1993).

In conclusion, VFM determination based on ultrasonography and hydrodensitometry was shown to be valid in assessing visceral fat volume. Ultrasonic devices have many advantages (e.g. easy operation, real-time visualization of tissues, non-invasive measurement) enabling easy accessibility to testing on a large number of subjects. The present method could be widely used to give significant information especially in the field of preventive medicine for promoting and maintaining good health and fitness.

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Table 4 Correlation matrix between visceral adipose tissue area obtained on 3 abdominal images and estimated visceral Fat mass

<table>
<thead>
<tr>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<tbody>
<tr>
<td>1) Visceral Fat Mass</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2) Visceral AT Area (Umbilicus)</td>
<td>0.75</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3) Visceral AT Area (+3.5cm)</td>
<td>0.78</td>
<td>0.88</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4) Visceral AT Area (-3.5cm)</td>
<td>0.77</td>
<td>0.95</td>
<td>0.89</td>
<td>-</td>
</tr>
</tbody>
</table>

*Derived from B-mode ultrasonic measurements. +3.5cm, transverse abdominal image acquired 3.5cm above umbilicus level; -3.5cm, transverse abdominal image acquired 3.5cm below umbilicus level, respectively. Coefficients shown are significant at 0.01 level.

Fig. 1 Relationship between VFM and MR-measured visceral AT area (umbilicus level).
MRI measurements.

References


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