A Technique for the Measurement of Visceral Fat by Ultrasonography: Comparison of Measurements by Ultrasonography and Computed Tomography

Masashi HIROOKA, Teru KUMAGI, Kiyotaka KUROSE, Seiji NAKANISHI,
Kojiro MICHITAKA*, Bunzo MATSUURA, Norio HORIIKE and Morikazu ONJI

Abstract

Objective This study aims to create a method of calculating intra-abdominal visceral fat volume by using ultrasound (US). The visceral fat volume measured by US was evaluated by comparison with the volume measured by computed tomography (CT).

Methods Eighty-seven patients (52 males and 35 females) were enrolled in this study. Both US and CT were performed, and the visceral fat volume was measured. Both the distance and thickness of the parameters in US were measured as follows: 1) the distance between the internal surface of the abdominal muscle and the splenic vein, 2) the distance between the internal surface of the abdominal muscle and the posterior wall of aorta on the umbilicus, and 3) the thickness of the fat layer of the posterior right renal wall.

Results The equation was calculated as follows: [visceral fat volume] = $-9.008 + 1.191 \times [\text{distance between the internal surface of the abdominal muscle and the splenic vein (mm)}] + 0.987 \times [\text{distance between the internal surface of the abdominal muscle and the posterior wall of the aorta on the umbilicus (mm)}] + 3.644 \times [\text{thickness of the fat layer of the posterior right renal wall (mm)}]$. There was a good correlation between the visceral fat volume calculated by the above equation and the volume by CT described ($r=0.860$, $p<0.0001$).

Conclusion The measurement of the visceral fat volume using US provided results as effectively as CT, and it was proven to be a useful method.
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Key words: visceral fat volume, ultrasonography

Introduction

Obesity is an important risk factor in diabetes mellitus, hypertension, hyperlipidemia, and cardiovascular diseases. Recently, metabolic syndrome has been suggested as being an accumulation of several conditions, such as glucose intolerance, hypertension, and hyperlipidemia in individual patients. There have been a number of reports on this syndrome that indicate a relation with insulin resistance, which causes syndrome X (insulin resistance, impaired glucose tolerance, hyperinsulinemia, increase in low-density lipoprotein, low high-density lipoprotein, and hypertension) (1), the deadly quartet (upper-body obesity, glucose intolerance, hypertriglyceridemia, and hypertension) (2), and insulin resistance syndrome (obesity, non-insulin-dependent diabetes mellitus, hyperinsulinemia, hyperlipidemia, and coronary artery disease) (3).

Moreover, nowadays, the distribution disorder of fatty tissue, especially with the higher accumulation of visceral fat among the various kinds of obesity, complicates metabolic disorders; this has been reported as visceral fat syndrome (visceral fat accumulation, glucose intolerance, hyperlipidemia, and hypertension) (4–6).

Evaluation of visceral fat has been conducted using waist-to-hip circumference ratio (7, 8) and several images using CT (9–12), magnetic resonance imaging (MRI) (13–17), or US (18–22). Of these methods, evaluation using CT is the most useful and popular method. However, CT exposes the patient to ionizing radiation, and MRI is much more expensive than other methods.

This study aims to create a novel method of easily calculating intra-abdominal visceral fat volume by using US, which does not expose the patient to ionizing radiation. The visceral fat volume measured by US was evaluated by comparison with the volume measured by CT.

From the Third Department of Internal Medicine and *the Endoscopy Center, Ehime University School of Medicine, Ehime

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Reprint requests should be addressed to Dr. Morikazu Onji, the Third Department of Internal Medicine, Ehime University School of Medicine, Shizukawa, Touon, Ehime 791-0295

Materials and Method

Patients

Eighty-seven patients (52 males and 35 females) who were admitted to our department between June 2002 and June 2003 were enrolled in this study. The mean age was 54.9 ± 16.7 years. The mean BMI was 25.3 ± 2.92 . Of these patients, 38 had chronic liver disease, 29 had gastrointestinal disease, 10 had diabetes mellitus, 5 had gall bladder stone, 3 had common bile duct stone, and 2 had thyroid disease. Patients with a history of abdominal operation, ascites, malignant disease, and severe hepatic failure were excluded from this study. US and CT were performed in these patients for evaluating visceral fat.

Moreover in order to confirm reproduction by well experienced sonographers in abdominal ultrasound, 5 healthy volunteers (mean BMI: 23.2 ± 3.64) were enrolled. These volunteers underwent US only in order to confirm reproduction of US. The mean age was 28.0 ± 2.91 years, and they had no disease. We obtained informed consent from all patients.

Biochemical study

The height (cm) and weight (kg) of each patient was measured, and body mass index (BMI, kg/cm^2) was calculated. Aspartate aminotransferase (AST), alanine aminotransferase (ALT), fasting plasma glucose, uric acid, total cholesterol, triglyceride, high-density lipoprotein (HDL) cholesterol, and leptin in sera were measured. The 75-g oral glucose tolerance test was performed in all patients. The 36 patients with a BMI of more than 25 were divided into 2 groups; the non-visceral fat type (subcutaneous fat type; $n=12$), and the visceral fat type ($n=24$). By calculating the fat volume used for these patients by US, visceral fat type was considered as more than 100 cm^3 and non-visceral fat type was less than 100 cm^3 . Height, weight, and BMI were expressed as mean $\pm$ SD. The biochemical markers described above were also compared among these 2 groups.

Ultrasonography

Within 3 days, US (SSD-6500 ultrasound machine, ALOKA, Tokyo, Japan) and CT were performed after an overnight fast, and the visceral fat volume was measured in the supine position at the end of a normal exhalation. Both the distance and the thickness of the parameters were measured as follows: 1) the distance between the internal surface of the abdominal muscle and the splenic vein (Fig. 1a), 2) the distance between the internal surface of the abdominal muscle and the posterior wall of the aorta on the umbilicus (Fig. 1b), 3) thickness of the fat layer of the posterior right renal wall in the right posterior perinephric space (Fig. 1c), and 4) the thickness of both the subcutaneous and preperitoneal fat layers in the xiphoid process (Fig. 1d). A 3.5-MHz convex-array probe was used to measure each parameter, other than the thickness of both the subcutaneous and the preperitoneal fat layers at the xiphoid process by performing a longitudinal scan, which was measured using a 7.5-MHz linear-array

Figure 1. Parameter for visceral fat measured by ultrasonography. Both the distance and the thickness of the parameters were measured: a) the distance between the internal surface of abdominal muscle and splenic vein, b) the distance between the internal surface of the abdominal muscle and the posterior wall of the aorta on the umbilicus, c) the thickness of the fat layer of the posterior right renal wall, d) the thickness of both the subcutaneous and preperitoneal fat layers in the xiphoid process.

probe. The transducer was placed vertically against the skin as lightly as possible to prevent compression of the fat layers. The distance between the internal surface of the abdominal muscle and the splenic vein was scanned transversely in the midline. When the splenic vein could not be visualized clearly, this vein was detected by using color doppler flow. This distance could be measured for all patients.

To confirm reproduction, we used this method on 5 healthy volunteers, measuring each parameter twice, 3 days after the first investigation. Moreover, two experienced sonographers performed US on these volunteers to confirm reproduction. For serial observation of visceral fat, the progress of the 5 patients with diabetes mellitus who had a BMI of over 30 was followed using both US and CT at 0, 3 and 6 months under diet therapy. These patients underwent diet therapy and physical exercise.

CT scanning

CT was performed in the supine position, using a LightSpeed Ultra 16 (GE Medical Systems, Milwaukee, WI). The interval of the single scan was 10 mm in the abdominal area. The visceral fat volume was calculated at the fourth lumbar vertebra according to the previous reports (9–12).

Statistical analysis

Student's *t*-test for unpaired samples was used to analyze the significance of difference in biochemical measurements between the visceral fat type group and the non-visceral fat

Figure 2. Relation between parameters of US and fat volume measured by CT. A) The distance between the internal surface of the abdominal muscle and the splenic vein ($r=0.801$, $p<0.0001$), B) the distance between the internal surface of the abdominal muscle and the posterior wall of aorta on umbilicus ($r=0.813$, $p<0.0001$), C) the thickness of the fat layer of the posterior right renal wall ($r=0.719$, $p<0.0001$).

type group. Pearson's correlation coefficients were calculated to assess the association among the factors using US, and the visceral fat volume was calculated using CT. Multivariate analysis with a stepwise selection process was used. P values of less than 0.05 were considered significant. Data analysis was performed using the computer program SPSS, Version 10.0 (SPSS Inc., Chicago, USA).

Results

Two different experienced sonographers measured these parameters of visceral fat for five healthy volunteers. The distance between the internal surface of the abdominal muscle and the splenic vein and the visceral fat volume was 3.58 ± 0.60 cm and 3.50 ± 0.62 cm, respectively ($p=0.841$). The internal surface of the abdominal muscle and the posterior wall of the aorta on the umbilicus was 3.20 ± 1.28 cm and 3.12 ± 1.16 cm, respectively ($p=0.92$). The thickness of the fat layer of the posterior right renal wall was 5.80 ± 2.68 mm and 5.80 ± 2.49 mm, respectively ($p=0.94$). There were no

Figure 3. Relation between visceral fat volume by US and by CT. A good correlation between visceral fat volume by US and by CT was seen ($r=0.860$, $p<0.0001$).

Figure 4. Serial observation in 5 patients who had a BMI of more than 30. In Cases 1 and 2, the fat volume using both CT and US decreased, and the body weight also decreased. When there were no changes in body weight, the calculated fat volumes were not decreased.

significant differences for in these parameters between the two experienced sonographers.

Multivariate analysis was performed to obtain the significant contributing factors to predict the visceral fat volume. In the investigation of the relation between the factors measured using US and the visceral fat volume calculated using CT, there was a significant correlation between the distance between the internal surface of the abdominal muscle and the splenic vein and the visceral fat volume ($r=0.801$, $p<0.0001$, Fig. 2A). The internal surface of the abdominal muscle and the posterior wall of the aorta on the umbilicus ($r=0.813$, $p<0.0001$, Fig. 2B) and the thickness of the fat layer of the posterior right renal wall ($r=0.719$, $p<0.0001$, Fig. 2C) also significantly correlated with the visceral fat volume.

Using multivariate analysis, the equation for the visceral fat volume was calculated as follows: [visceral fat volume] = $-9.008 + 1.191 \times [\text{The distance between the internal surface of the straight muscle and the splenic vein (mm)}] + 0.987 \times [\text{The distance between the internal surface of the straight muscle and the posterior wall of the aorta on the umbilicus (mm)}] + 3.644 \times [\text{the thickness of the fat layer of the posterior right renal wall with a significant correlation (mm)}]$. There was a strong correlation between the visceral fat volume calculated from the above equation and the volume by CT described ($r=0.860$, $p<0.0001$, Fig. 3). In 5 volunteers, there was no significant difference between the fat volumes at the first US (86.4 ± 25.3 cm²) and the second US (84.7 ± 24.9 cm², $p=$

0.915).

In 5 patients who had a BMI of more than 30, we prospectively performed CT and US for 3 times. In Cases 1 and 2, the fat volume using both CT and US decreased, and the also body weight decreased. In the subjects who showed no change in body weight, the calculated fat volumes did not decrease (Fig. 4).

Using the visceral fat volume calculated by US, we compared the biochemical markers in 36 patients having a BMI of more than 25. Of 36 patients who had a BMI of more than 25, the rate of non-visceral fat type patients was 33%. Fasting plasma glucose ($p<0.05$), total cholesterol ($p<0.05$), LDL-cholesterol ($p<0.01$), free fatty acid ($p<0.01$), leptin ($p<0.01$) and HOMA-R ($p<0.01$) were increased in the visceral fat group (Table 1).

Discussion

Excessive accumulation of adipose tissue causes obesity. There have been many reports on the significance of visceral fat volume (4–6). Some groups report that obese people with more than 100 cm² of visceral fat volume have a higher complication rate of diabetes mellitus and coronary disease (7, 23). Therefore, a visceral fat volume of over 100 cm² is widely accepted in diagnosing visceral fat obesity. However, if only weight or BMI are measured, this is not diagnosed as visceral fat type. Of the patients who had a BMI of more

Table 1. Comparison of Biochemical Markers

	Non visceral fat group	Visceral fat group	
N	12	24	
Age (years)	55.3±17.3	55.7±15.2	
Body mass index (kg/cm ²)	27.2±1.41	28.2±3.3	
Fasting plasma glucose (mg/dl)	94.8±9.50	128.6±43.1	*
Hemoglobin A1c (%)	5.3±1.3	6.1±1.2	
Total cholesterol (mg/dl)	177.7±36.7	207.3±31.8	*
Triglyceride (mg/dl)	130.1±44.2	154.9±51.1	
High density lipoprotein (mg/dl)	56.3±16.2	47.6±14.0	
Low density lipoprotein (mg/dl)	96.5±37.0	129.6±28.7	**
Nonesterified fatty acid (mEq/l)	0.34±0.23	0.72±0.18	**
Uric acid (mg/dl)	5.7±1.7	5.7±1.2	
Alanine transferase (IU/l)	42.3±24.9	73.9±56.9	
Leptin (ng/ml)	12.8±4.40	19.9±5.65	**
Homeostasis model assessment	2.14±1.14	5.76±2.71	**

*p<0.05, **<0.01.

than 25 which had been thought to be the visceral fat type (7), the rate of non-visceral fat type patients was 33%. This suggests that BMI is not a useful method for detecting the visceral fat type. So in order to diagnose visceral fat type, it is better to perform abdominal images (i.e. CT, MRI, or US). Both CT and US have been widely used and have been effective in many fields. CT, however exposes patients to ionizing radiation, whereas US does not expose the patient to such radiation. There have been no methods for easy and accurate diagnosis of visceral fat obesity. However, we have developed a new, simple and accurate method of measuring visceral fat volume using US.

We have noted that the splenic vein is unclear in obese people due to the accumulation of visceral fat. So we focused on the distance between the internal surface of the abdominal muscle and the splenic vein (Fig. 1a), which to date has not been considered as a factor. Other distances, which have been studied previously, were also measured (20–22). The distance between the internal surface of the abdominal muscle and the splenic vein was as useful as the distance between the internal surface of the abdominal muscle and the posterior wall of aorta on the umbilicus and the thickness of the fat layer of the posterior right renal wall. In those reports (20–22), only a single parameter was used. Thus, to obtain a stronger correlation with the visceral fat volume using CT, we produced a novel equation using multivariate analysis. We measured each parameter twice in 5 healthy volunteers, and found that the role of US is important, there being less difference between the 2 measurements. Moreover, 2 experienced sonographers measured the parameter, and calculated fat volumes that were not significantly different. Thus, this method has a good reproduction. In the following patients with decreasing body weight and fat volume according to CT, the fat volume using US was also decreased. Thus, the method that uses US is useful to evaluate the efficacy of diet therapy and physical exercise.

In addition in the 36 patients in the present study who had a BMI of more than 25 (which had been thought as visceral fat type) (7), the rate of non-visceral fat type patients was 33%. In the visceral fat type group, HOMA-R, fasting plasma glucose, total cholesterol, and LDL-cholesterol were significantly high. Obese people in the visceral fat type group show insulin resistance, and are a high-risk group for metabolic disorders because free fatty acids and leptin were significantly high. Thus, the patients who had a BMI of more than 25 should be divided into 2 groups based on ultrasonography.

In conclusion, the measurement of visceral fat volume using US could calculate as effectively as using CT. This method should be practiced in clinics due to its low cost, no side effects, and technical suitability.

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