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Body Fat Assessment Method Using CT Images with Separation Mask Algorithm

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Abstract In recent years, the number of obese population in Korea has been growing up along with the economic development, environmental factors, and the change in life style. Considering the growth of obese population and the adverse effect of obesity on health, it is getting more important to prevent and diagnose the obesity with the quantitative measurement of body fat that has become an important indicator for obesity. In this study, we proposed a procedure for the automated fat assessment from computed tomography (CT) data using image processing technique. The proposed method was applied to a single-CT image as well as CT-volume data, and results were correlated to those of dual-energy X-ray absorptiometry (DEXA) that is known as the reliable method for evaluating body fat. Using single-CT images, correlation coefficients between DEXA and the automated assessment and DEXA and the manual assessment were 0.038 and 0.058, respectively ($P>0.05$). Hence, there was no significant correlation between three methods using the proposed method with single-CT images. On the other hand, in case of CT-volume data, the above correlation coefficients were increased to 0.826, 0.812, and 0.805, respectively ($P<0.01$). Thus, DEXA and the proposed methods with CT-volume data showed highly significant correlation with each other. The results suggest that the proposed automated assessment using CT-volume data is a reliable method for the evaluation of body fat. It is expected that the clinical application of the proposed procedure will be helpful to reduce the time for the quantitative evaluation of patient's body fat.

Keywords Body fat · Fat assessment · Computed tomography (CT) · DEXA · Separation mask

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Introduction

Obesity is the status of a body with excessive body fat. Since obesity often becomes the cause of diverse chronic diseases, it is an emerging serious problem among public health issues. The number of obese population has dramatically been increasing all over the world including US along with the economic development and changes in environmental factors and life style. During 20 years from 1988 to 2008, the level of obesity in American population has been increased by 12 % in male population and 10.1 % in female population [1]. Considering the growth of obese population and the adverse effect of obesity on health, it is getting more important to prevent and diagnose the obesity with the quantitative measurement of body fat that has become an important indicator for obesity.

There are some methods available for the measurement of body fat including body mass index (BMI), waist–hip ratio (WHR), bioelectrical impedance (BIA), computed tomography (CT)-based measurement, and dual-energy X-ray absorptiometry (DEXA). Although BMI, WHR, and BIA are widely used to calculate body fat, results from these methods do not adequately represent the actual amount of body fat and are affected by many factors including inter- and intra-observer variability [2–5]. DEXA, the most commonly used method to estimate bone mineral density, is used to measure the accurate amount of body fat by excluding measured bone mass. DEXA is becoming more popular in Korea since it utilizes a low dose of radiation and provides validated accurate measurement of body fat. However, the drawback of DEXA is that it cannot provide the information on the distribution of body fat such as discriminating between subcutaneous and visceral body fat [5, 6]. Clinically, visceral obesity is different form subcutaneous obesity, because the visceral obesity has been known to be related with metabolic syndrome [7].

Although CT uses higher dose of X-rays compared with DEXA, CT-based measurement of body fat can directly compute the amount of body fat and discriminate visceral fat from subcutaneous fat from results. Radiation exposure can be minimized by using low-dose CT scanning, or additional radiation exposure can be avoided by utilizing CT taken for other purposes such as health screening. However, CT-based fat delineation is a time-consuming procedure since clinicians have to manually define the regions of body fat [2, 6]. To overcome such drawback, many studies have been reported to automate the quantification of body fat using CT images with the image processing technology [8–13]. To differentiate between visceral and subcutaneous fat in CT images, Bandekar et al. (2005) [8] have proposed automatic fat analysis in computed tomography based on fuzzy affinity and active shape model. The performance of this method was evaluated by measures of accuracy and sensitivity compared with results of manual quantification by experts. This method showed the accuracy of 98.29±0.62 % for subcutaneous fat and 97.66±0.98 % for visceral fat. In case of sensitivity, it was 90.01±3.77 % for subcutaneous fat and 86.14±7.25 % for visceral fat [8]. Zhao et al. (2006) [13] have presented a method to automatically quantify visceral and subcutaneous fat distribution on volumetric computed tomographic (CT) data using pixel information along radii drawn from the center of the body at an increment of 3°. When results using this method and manual measurement by radiologist for nine subjects were compared, the differences between automatic and manual methods were 1.54 % for visceral fat and 0.65 % for subcutaneous fat [13].

Studies mentioned above only reported methods of automatic body fat evaluation based on image processing technique and results in comparison with manual assessment using same CT data. To our knowledge, there is no study to compare the performance of automatic evaluation of body fat using image processing with those of various fat assessment methods, except manual segmentation of fat using CT. Thus, in the present study, we propose the analytic method based on CT volume for the measurement of body fat amount and distribution, which was compared with manual assessment method using CT and DEXA.

Materials and Methods

CT data were collected from ten subjects (five male and five female patients; age range, 22.2–62.8 years) who were in- or outpatients at the Seoul National University Hospital. The experimental protocol was approved by the institutional review board of Seoul National University Hospital, and all subjects gave written informed consent for the study before participation.

CT scan were performed with all subjects in the supine position using Sensation 16 (SIEMENS, Germany; field of view of 320×320 mm, matrix of 512×512, slice thickness of 3 mm, 120 kVp, 58 mAs, 1,524 pixel per mm resolution).

From each patient, one slice of CT data was collected at the location of umbilicus between fourth and fifth lumbar vertebrae (L4–5) as shown in Fig. 1. For CT-volume data, six additional CT images were collected from above and below the umbilicus of each patient, respectively. Collected CT data were applied to both of manual and automatic body fat assessment methods. For manual assessment, an expert delineated the regions of visceral and subcutaneous fat using ImageJ (ver. 1.60, National Institute of Health, USA). The three-compartment DEXA, which separates body composition into bone, lean body mass, and fat materials, was

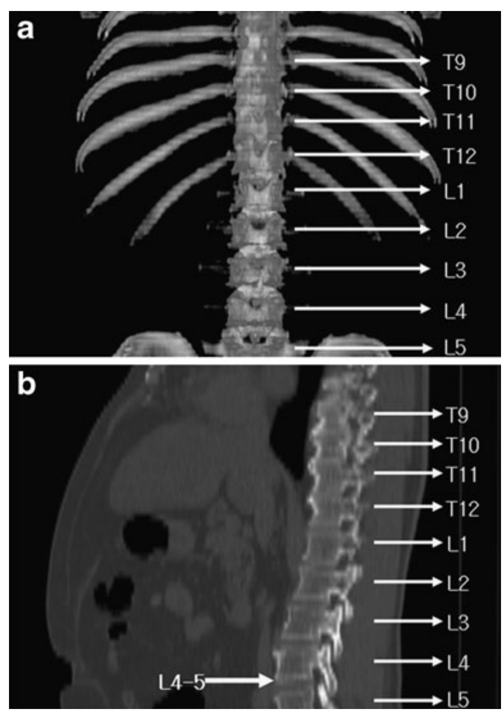
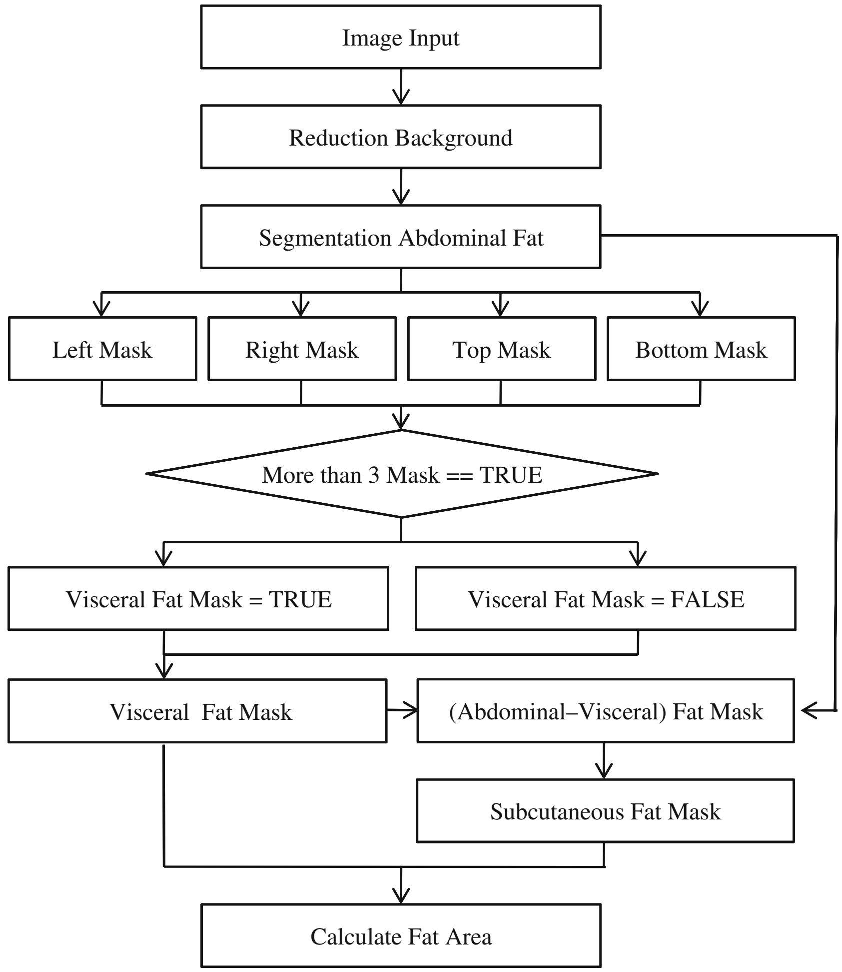


Fig. 1 Location of vertebrae lumbales L4–5; **a** coronal view; **b** sagittal view

Fig. 2 Algorithm flowchart



applied to the CT data using the whole-body DEXA scanner, LUNAR Prodigy Vision scanner (software version 9.30, GE Healthcare, USA). It means that the same patients who had CT scans were scanned using DEXA. The analysis tool for automatic body fat assessment from the CT data was developed using Microsoft Visual Studio (Ver. 2005, Microsoft, USA). The automated assessment of body fat from CT data was performed using a protocol described in Fig. 2.

1. Subtracting background

   Although acquired CT images can broadly be divided into two compartments of body and air, they also include unnecessary background such as bed and sheets near the body. Since these unnecessary parts may affect the assessment of body fat, they were removed using thresholding and labeling techniques before the body fat determination. The pixel value of air in HU (Hounsfield unit) is known to be as low as about −1,000 [14]. Thus, considering the background noise of CT images, all regions below −900 HU were subtracted to remove air compartments. Then, unnecessary areas such as bed and sheets were removed by labeling all regions followed by removing all regions except the largest region, the body. With all background removed, the segmentation and assessment of body fat were performed only in the area of upper body.
2. Thresholding

   Prior to the delineation between visceral fat and subcutaneous fat, a binary image representing regions of body fat was made by thresholding. The CT image taken between the fourth and fifth lumbar vertebrae includes the areas of skin, muscle, bone, intestine, and fat. It has been reported that the ranges of pixel values of body fat is between −190 and −30 HU [15]. Hence, pixels with values in the range between −190 and −30 HU were detected as body fat during the thresholding process. The segmented body fat was then represented as a binary image by assigning label ‘T’ to the fat area (value=255) and label ‘F’ to the non-fat area (value=0).
3. Differing the visceral fat from the subcutaneous fat

   In this study, a segmentation mask was made from the thresholded binary image and used to differentiate visceral fat from subcutaneous fat. A thresholded binary image (Fig. 3) shows visceral fat surrounded by subcutaneous fat

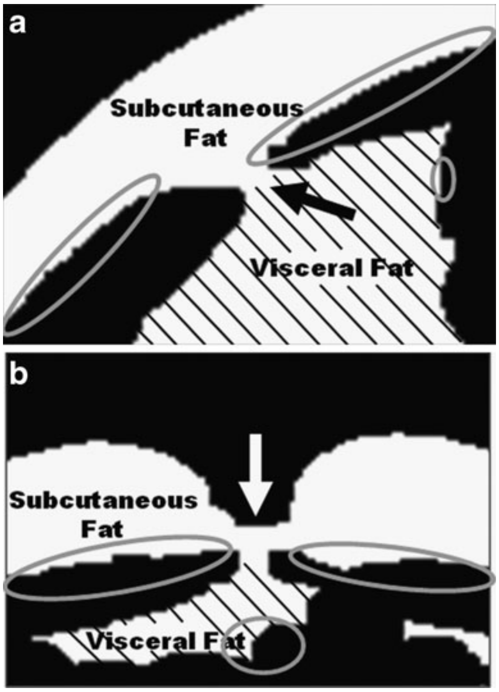


Fig. 3 Initial point of scanning on segmentation mask; **a** left to right direction, **b** top to bottom direction

with bones and other organs removed by thresholding process. However, it was observed that visceral and subcutaneous fat were connected to each other in some cases, and the patterns of such connection were not consistent. In this study, the segmentation mask of non-subcutaneous fat area was made to separate regions of visceral fat and subcutaneous fat.

The segmentation mask was computed from four preliminary masks with different scanning directions, left to right, right to left, top to bottom, and bottom to top. Each preliminary mask was created by assigning 'True' value from the first 'False' pixel after subcutaneous fat was detected in the binary image to the last pixel in the designated scanning direction. When subcutaneous fat and visceral fat are connected, detected borders between subcutaneous and visceral fat in some primary masks were located in the regions of visceral fat as shown in Fig. 3. To resolve this problem, the segmentation mask was created using a modified bit-AND operation of four primary masks. The modified bit-AND operation of matching pixels from four binary images is defined to be true if three or more pixels have true value, while the original bit-AND operation of four variables is true only if all variables have true value. With the modified bit-AND operation, the segmentation mask surrounding areas of visceral fat was made from four preliminary masks (Fig. 4a).

The subcutaneous fat was segmented by subtracting the segmentation mask from the thresholded binary image (Fig. 4b). Due to variations among individuals, the distribution of visceral fat surrounding inner organs is hard to be quantified with the standard thresholding value for the detection of body fat. Thus, the threshold values for the

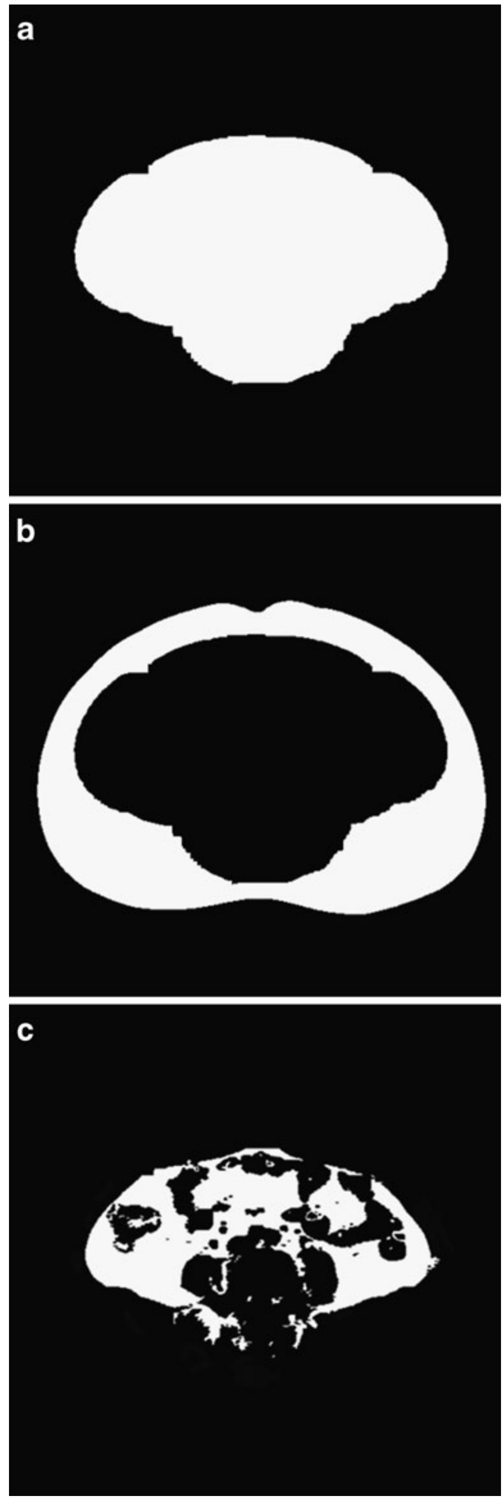


Fig. 4 **a** The segmentation mask using modified AND operation; **b** the subcutaneous fat by subtracting the segmentation mask; **c** the visceral fat by applying the threshold limits in the area of the segmentation mask

visceral fat were separately determined using the distribution of pixel values in the region of the subcutaneous fat. Using the mean and standard deviation (SD) of pixel values in the subcutaneous fat, the upper and lower limits of thresholding value were quantified as mean±(2×SD), respectively [16]. The region of visceral fat was segmented by applying the upper and lower threshold limits to CT images in the area of the segmentation mask (Fig. 4c).

Results

In this study, we developed a method to make the segmentation mask for differentiating subcutaneous and visceral fat from thresholded binary images of background-extracted CT images. Using the segmentation mask, the subcutaneous fat was efficiently segmented from a CT image. Then, the visceral fat was detected and measured using the information of pixels in the subcutaneous fat. Figure 5 shows representative results of the segmentation of subcutaneous and visceral fat using the proposed method. Regions of interest outlined by white line indicates regions of subcutaneous fat, and gray-scale areas wrapped by subcutaneous fat are areas where visceral fat were detected.

To evaluate the performance of the proposed method for the automatic assessment of body fat, we calculated correlations among the amounts of fat detected using the DEXA, the manual assessment, and the proposed automated assessment using CT images.

Table 1 shows amounts of fat (n=10) measured using DEXA and automatic and manual assessments of fat using CT data. Automatic and manual CT-based methods were applied to each of single-CT image at the location of umbilicus and CT volume data. In CT-based methods, the amounts of body fat were measured in the number of pixels in the regions of visceral and subcutaneous fat, respectively.

Table 2 shows correlations among results from DEXA and automatic and manual assessments using CT volume data. The result of DEXA was most correlated to that of automated assessment using CT volume data (r=0.826, P< 0.01). Correlation coefficients between DEXA and manual assessment using CT volume data and between automatic and manual assessment using CT volume data were 0.812 and 0.805, respectively (P<0.01). In case of CT volume data, correlation coefficients between automatic and manual assessment was 0.834 (P<0.01) for subcutaneous and 0.722 (P<0.05) for visceral. Results showed that tested three methods were significantly correlated among each other.

Table 3 shows correlations among results from DEXA and automatic and manual assessment using CT volume data. The result of DEXA was most correlated to that of automated assessment using CT volume data (r=0.038, P> 0.05). Correlation coefficients between DEXA and manual

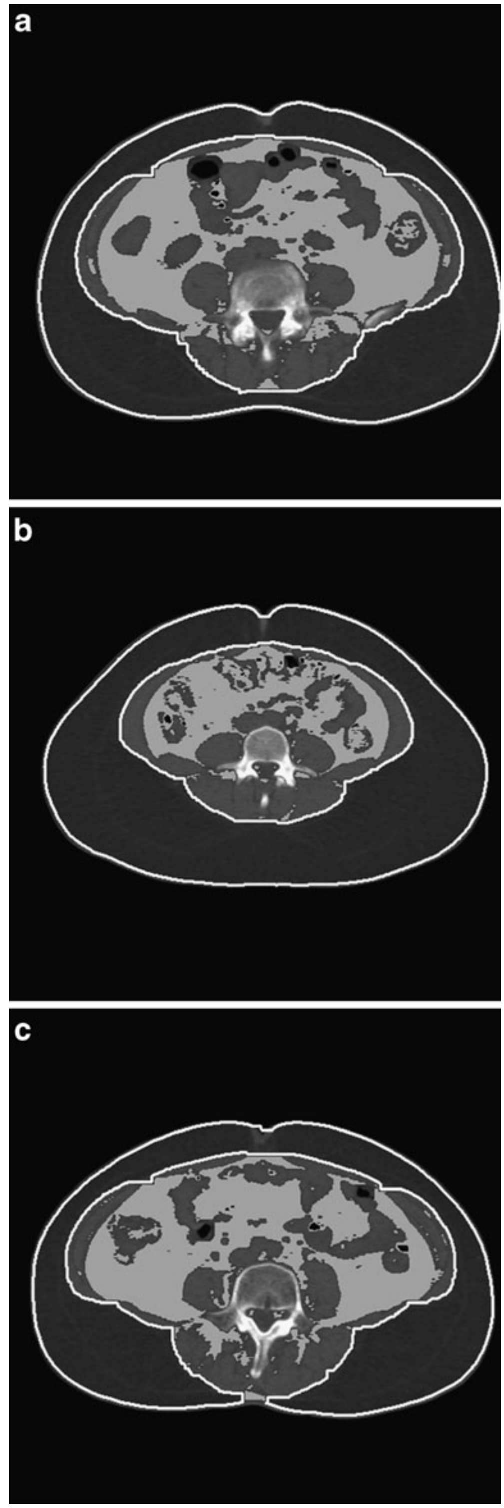


Fig. 5 Result of the segmentation of subcutaneous and visceral fat: **a** case1, **b** case2; **c** case3

assessment using CT volume data and between automatic and manual assessment using CT volume data were 0.058 (P>0.05) and 0.921 (P<0.01), respectively. In case of CT slice data, correlation coefficients between automatic and manual assessment was 0.991 for subcutaneous and 0.924

Table 1 Result of assessment (DEXA and CT images)

Index	Location	CT slice (pixel)		CT Volume (pixel)		DEXA (g)
		Automatic	Manual	Automatic	Manual	
1	Subcutaneous	46,443	42,800	506,858	470,818	20,422
	Visceral	28,764	24,420	361,673	246,277	
	All	75,207	67,220	868,531	717,095	
2	Subcutaneous	35,529	32,075	497,829	426,346	23,618
	Visceral	27,193	23,090	460,913	271,131	
	All	62,722	55,165	958,742	697,477	
3	Subcutaneous	27,139	27,550	267,394	289,604	19,531
	Visceral	27,522	28,355	336,767	289,083	
	All	54,661	55,905	604,161	578,687	
4	Subcutaneous	34,082	31,050	547,504	382,603	25,733
	Visceral	23,714	22,601	430,804	400,953	
	All	57,796	53,651	978,308	783,556	
5	Subcutaneous	36,627	34,836	435,133	279,921	23,050
	Visceral	30,689	23,415	436,022	338,106	
	All	67,316	58,251	871,155	618,027	
6	Subcutaneous	37,865	34,344	325,419	387,105	19,823
	Visceral	34,899	26,165	314,868	283,151	
	All	72,764	60,509	640,287	670,256	
7	Subcutaneous	40,171	38,717	388,075	455,494	24,568
	Visceral	40,324	37,265	415,728	347,766	
	All	80,495	75,982	803,803	803,260	
8	Subcutaneous	59,822	57,923	807,237	726,505	40,343
	Visceral	13,820	9,261	282,837	124,670	
	All	73,642	67,184	1,090,074	851,175	
9	Subcutaneous	31,643	29,875	272,055	346,988	16,986
	Visceral	33,555	28,553	335,219	258,133	
	All	65,198	58,428	607,274	605,121	
10	Subcutaneous	50,433	48,394	319,587	360,071	15,818
	Visceral	30,703	26,046	214,402	201,678	
	All	81,136	7,4440	533,989	561,749	

for visceral ($P<0.01$). Results showed that tested three methods were nonsignificantly correlated among each other, except for result between automatic and manual assessments.

Discussion

In this study, we have proposed the automated assessment of body fat using CT data and compared the results with those of DEXA conducted at Seoul National University Hospital as well as with the results of manual assessment using CT data by experts. Results of manual and automated assessment using CT data were correlated to results of DEXA that is a well-accepted method for fat assessment. Using CT-based automated and manual assessment methods, the amounts of body fat were measured using CT-volume data and a CT image at the location of umbilicus and correlated to results from other methods (Tables 2 and 3). Using CT-

Table 2 Result of correlations among the amounts of fat detected using the DEXA, the manual assessment, and the proposed automated assessment using CT volume

Method	Avg ± SD	Avg ± SD	Correlation
DEXA and automatic	22,989.2±6,892.9	795,632.4±189,292.6	0.826*
DEXA and manual	22,989.2±6,892.9	688,640.3±99,968.2	0.812*
Automatic and manual			
All	795,632.4±189,292.6	688,640.3±99,968.2	0.805*
Subcutaneous	436,709.1±164,138.2	412,545.5±127,060.9	0.834*
Visceral	358,923.3±77,757.8	276,094.8±77,813.0	0.722**

*$p<0.01$, significant correlation

**$p<0.05$, significant correlation

Table 3 Result of correlations among the amounts of fat detected using the DEXA, the manual assessment, and the proposed automated assessment using CT slice

Method	Avg ± SD	Avg ± SD	Correlation
DEXA and automatic	22,989.2±6,892.9	69,093.7±9,076.3	0.038
DEXA and manual	22,989.2±6,892.9	62,673.5±8,044.6	0.058
Automatic and manual			
All	69,093.7±9,076.3	62,673.5±8,044.6	0.921*
Subcutaneous	39,975.7±9,715.3	37,756.4±9,486.3	0.991*
Visceral	29,118.3±7,096.7	24,917.1±6,965.4	0.924*

*$p<0.01$, significant correlation

volume data, results showed significant correlation among the three methods as shown in Table 2. However, using single-CT image, correlations between the assessment methods were significantly low.

Correlation coefficients between DEXA and the automated assessment method were 0.038 ($P>0.05$) and 0.826 ($P<0.01$) with one CT image and CT-volume data, respectively. Using the same data, correlation coefficients between DEXA and the manual assessment method were 0.058 ($P>0.05$) and 0.812 ($P<0.01$) with one CT image and CT-volume data, respectively. The rationale for the low correlation between DEXA and the automated or manual assessment method with one CT image is that DEXA utilizes data from the whole-body scanner while a single-CT image only conveys information at one cross-section of the body.

In order to reduce such errors with single-CT images, we applied the automated as well as manual assessment methods to the CT-volume data and compared the results to those of DEXA. Significantly high correlation between the results implies that fat assessment using CT-volume data is more reliable than using a single-CT image. The reliability of the automated assessment method using CT-volume data was confirmed by its high correlation to the manual assessment using CT-volume data ($r=0.805$, $P<0.01$) as well as DEXA ($r=0.826$, $P<0.01$).

The major limitation of this study is the small number of specimens used in this study. It was due to the amount of experimental data obtained by means of DEXA that limited us to only ten cases for the assessment of body fat. For each CT-volume data, we could take only 13 CT images for evaluating body fat. Provided that more data by DEXA as well as the CT-volume data are collected in the future, the correlation between the DEXA and the automated and manual assessment methods is expected to be highly significant. The results obtained in this study suggest that the proposed automated fat assessment is time-saving.

In addition, when lipids accumulated excessively, visceral fat could have an effect on metabolic syndrome, leading to ectopic fat deposition in abnormal locations such as skeletal muscle, liver, heart, etc. [7]. However, a prediction of the effect is not easy because it is difficult to measure the amount of fat mass at specific area of the body by the common methods, including the DEXA method. Consequently, compared with other methods for measuring the amount of fat mass, we expect that our proposed method will contribute more to the clinical diagnosis in that it is possible to segment visceral fat and subcutaneous fat automatically in CT images and to evaluate them quantitatively by accurate measurement of each fat area based on three-dimensional volume reconstruction.

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