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FULL PAPER

Visceral adipose tissue area measurement at a single level: can it represent visceral adipose tissue volume?

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Objective: Measurement of visceral adipose tissue (VAT) needs to be accurate and sensitive to change for risk monitoring. The purpose of this study is to determine the CT slice location where VAT area can best reflect changes in VAT volume and body weight.

Methods: 60 plain abdominal CT images from 30 males [mean age (range) 51 (41–68) years, mean body weight (range) 71.1 (50.9–101.9) kg] who underwent workplace screenings twice within a 1-year interval were evaluated. Automatically calculated and manually corrected areas of the VAT of various scan levels using “freeform curve” region of interest on CT were recorded and compared with body weight changes.

Results: The strongest correlations of VAT area with VAT volume and body weight changes were shown in a slice 3 cm above the lower margin of L3 with r values of 0.853 and 0.902, respectively.

Conclusion: VAT area measurement at a single level 3 cm above the lower margin of the L3 vertebra is feasible and can reflect changes in VAT volume and body weight.

Advances in knowledge: As VAT area at a CT slice 3 cm above the lower margin of L3 can best reflect interval changes in VAT volume and body weight, VAT area measurement should be selected at this location.

INTRODUCTION

The prevalence of obesity has increased in recent years, worldwide, in countries both rich and poor, and among all segments of society.¹ Obesity is a state in which adipose tissue is accumulated excessively around the abdomen, while the World Health Organization uses body mass index to define obesity.² Abdominal adipose tissue can be classified into visceral adipose tissue (VAT) and subcutaneous adipose tissue (SAT): VAT is defined as adipose tissue inside the thorax, abdomen, and pelvis, whereas, SAT is defined as an adipose tissue layer existing between the dermis and aponeurosis or fascia.³ VAT is more easily accumulated in males than SAT, and the state in which VAT accumulates excessively is called metabolic syndrome.⁴ In addition, VAT deposits have been reported to be related to cardiovascular disease and Type 2 diabetes.^{5–7} As VAT is more relevant than SAT in such diseases, it is necessary to measure VAT separately.^{8,9}

In addition to studies demonstrating a transverse association between abdominal adipose tissue and disease risk factors, a recent study has explored the longitudinal associations between quantitative changes in VAT with

incidence and temporal changes in disease risk factors.⁸ It is necessary therefore to accurately measure VAT change over time.

Although total volume measurement of VAT using post-processing software is theoretically ideal for evaluating interval changes, there is a possibility that proper segmentation may not be automatically performed in the diaphragm or near the pelvis, and even after limiting the number of the slices to be measured, the segmentation of all the slices must be confirmed with or without correction. This procedure can be complicated and time consuming.

The purpose of this study is to determine the single CT slice location where VAT area best reflects changes in VAT volume and body weight.

METHODS AND MATERIALS

Subjects

Fifty healthy males from a cleaning company who underwent multiple annual workplace screenings at a local hospital

from 2012 to 2014 participated in this retrospective study. Participants were presented with the same information required in a written consent document, but documentation of the process has been waived by the Internal Review Board of our institution. Out of 135 plain abdominal CT studies in the 50 subjects, average $\pm$ standard deviation (range) of the scan interval in the same subject was 368 ± 16.7 (335–406) days. We excluded 20 of the subjects by allowing a difference of up to 2 weeks (14 days) to reduce the impact of the scan interval on VAT area, VAT volume and body weight. We included 60 studies from 30 subjects [mean age (range) 51 (41–68) years and mean body weight (range) 71.1 (50.9–101.9) kg] with 368 ± 12 (357–380) days' interval between baseline and follow-up CTs.

Image acquisition

All subjects underwent non-contrast CT using 64-slice multi-detector CT (Aquilion 64, Toshiba Medical Systems, Otawara, Tochigi, Japan) with imaging range from beneath the diaphragm to the upper margin of the pubic symphysis in a supine position under the following standardized conditions: tube voltage 120 kVp, tube current 400 mA, FOV 320 mm², gantry rotation time 0.5 s, collimation 0.5 mm, table feed 29.496 mm, reconstruction function FC13, reconstruction slice thickness 5.0 mm, matrix size 512 $\times$ 512, pitch 0.828.

Image analysis

VAT area measurement

CT data were loaded onto a dedicated workstation (SYNAPSE VINCENT, Fujifilm Corporation, Tokyo, Japan). VAT area measurement was performed with an automated analysis program installed in the workstation (Figure 1a). VAT area (cm²) was measured on each slice (5 mm thickness) using sagittal CT images (Figure 1b). Slices at the lower margin of the third lumbar vertebral body (L3) and at the umbilicus were included for VAT area measurement.¹⁰ A radiologist with more than 20 years of experience confirmed the appropriateness of the slice location determined by the automatic slice selecting function of the workstation and corrected the contouring of the VAT when needed. All the segmentations were performed utilizing “freeform curve” region of interest. For each slice, VAT was measured by applying predefined image display settings (window range: –190/–30 Hounsfield Units [HU]).¹¹

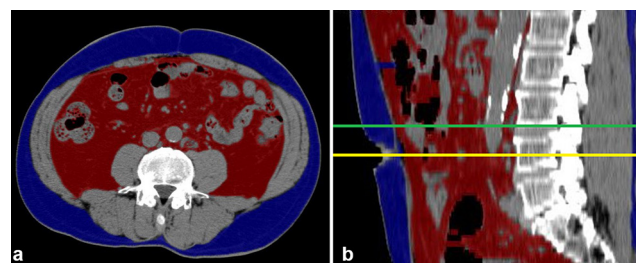
VAT volume measurement

In the subject with the shortest height (153.4 cm), there were 25 slices (12.5 cm) from the lower margin of L3 to beneath the diaphragm and 36 slices (18 cm) from the lower margin of L3 to upper margin of the pubic symphysis. VAT volume for all subjects was therefore determined as the sum of 62 slices (25 slices above and 36 slices below, plus the slice at the lower margin of L3) of VAT area multiplied by the slice thickness (5 mm).

For the 62 slices analysed, the error rate was calculated using the following formula:

$$\text{Error rate [\%]} = \frac{100 \times [(\text{area calculated by automatic contouring}) - (\text{area calculated by manual contouring})]}{(\text{area calculated by manual contouring})}$$

Figure 1. (a) Abdominal adipose tissue measurement using CT image by workstation. Subcutaneous and visceral adipose tissues are displayed in blue and in red, respectively. (b) Determination of slice levels at lower margin of the third lumbar vertebra and at the umbilicus. Slice levels at lower margin of the third lumbar vertebra (green line) and at umbilicus (yellow line) are indicated on the sagittally oriented image.



The error rate was calculated to demonstrate the magnitude of measurement error by the automatic method depending on the slice location of the abdominal CT.

Statistical analysis

SPSS version 22.0 (IBM Corp., New York, NY) for Windows was used for the statistical analysis. Pearson's correlation coefficients were generated between VAT area and VAT volume, interval change between VAT area and VAT volume and interval change between VAT area and body weight. Pearson's correlation coefficients were interpreted as follows: $r < 0.20$, poor correlation; $r = 0.20$ – 0.40 , fair correlation; $r = 0.41$ – 0.60 , moderate correlation; $r = 0.61$ – 0.80 , good correlation; and $r > 0.80$, excellent correlation.¹²

RESULTS

VAT area and volume calculated by automatic and manual contouring

Average VAT area of each slice position at baseline and follow-up calculated by automatic and manual contouring is shown in Figure 2. In 60 studies from 30 subjects, the error rates of all the 62 slices (from the diaphragm to the pubic symphysis) are shown in Figure 3. Figure 4 is a rescaled figure of the error rates of the 56 slices after eliminating the data of the upper abdomen. Mean VAT area at the diaphragm calculated by automatic contouring tended to be larger than that calculated by manual contouring, while mean VAT area at the pelvis calculated by manual contouring was larger than that calculated by automatic contouring. There were no statistically significant differences between the data obtained manually and automatically. At the slices from 8.5 cm above the lower margin of L3 to 14.5 cm below the lower margin of L3, the error rate was smaller than $\pm 5\%$. We therefore analysed VAT area and volume in this scan range.

Correlation between VAT area and volume

Pearson's correlation coefficients of VAT area with VAT volume for each slice are shown in Figure 5; there were excellent correlations at all slices with the exception of the slice 14.5 cm below the lower margin of L3. The strongest correlation of VAT area with VAT volume was shown in the slice 4 cm above the lower margin of L3 with an r value of 0.980.

Figure 2. Average VAT area of each slice position at baseline and follow-up calculated by automatic and manual contouring. (a) Automatic contouring calculation at baseline. (b) Manual contouring calculation at baseline. (c) Automatic contouring calculation at follow-up. (d) Manual contouring calculation at follow-up. VAT, visceral adipose tissue.



Correlation of interval change between VAT area and volume

Pearson's correlation coefficients of changes between VAT area and volume for each slice are shown in Figure 6. Excellent correlations were shown in the ranges from the slices 1.5 to 4 cm and the slice 8 cm above the lower margin of L3 with r values ranges of 0.808–0.902. The strongest correlation of VAT area and volume change was shown in the slice 3 cm above the lower margin of L3 with an r value of 0.902.

Correlation of interval changes between VAT area and body weight, and interval changes between VAT volume and body weight

Pearson's correlation coefficients of interval changes between VAT area and body weight, and interval changes between VAT volume

and body weight are shown in Figure 7. Excellent correlations were shown in the ranges from the slices 2 to 4 cm above the lower margin of L3 with an r value range of 0.808–0.902. The strongest correlations of change between VAT area and body weight were shown in the slice 3 cm above the lower margin of L3 with an r value of 0.853. In addition, the correlation of interval changes between VAT volume and body weight had an r value of 0.887.

Performance of VAT area at the umbilical slice

Pearson's correlation coefficients between VAT area at the umbilical slice and VAT volume (r value of 0.893), interval change between VAT area at the umbilical slice and VAT volume and interval changes between VAT area at the umbilical slice and body weight (r values of 0.529 and 0.490, respectively) are shown in Table 1.

Figure 3. Error rates of all 62 slices (from the diaphragm to the pubic symphysis).

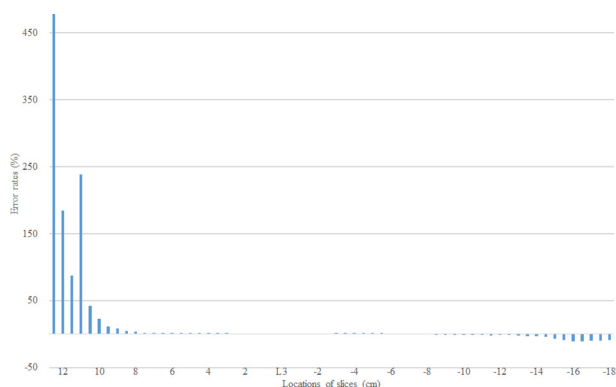


Figure 4. Error rates of 55 slices after eliminating the data of upper abdomen.

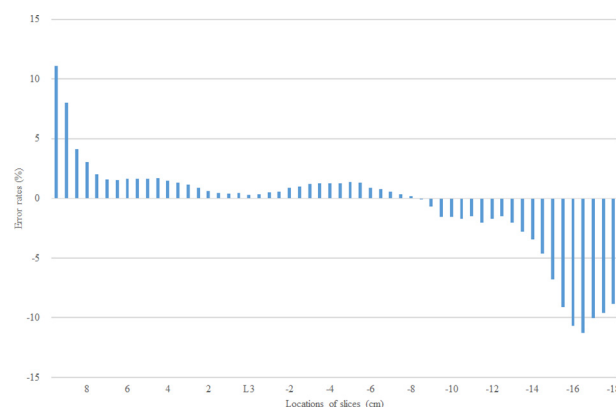
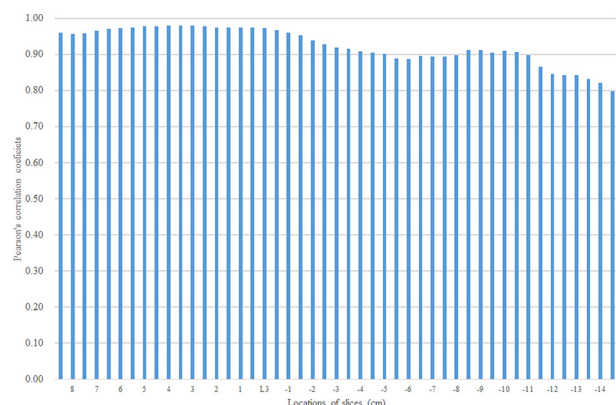


Figure 5. Correlation between VAT area and volume at each slice. VAT, visceral adipose tissue.



DISCUSSION

The association of VAT accumulation with morbidity^{13–15} and mortality¹⁶ has been clearly demonstrated using various measurement protocols. In a recent large community-based observational study, Lee *et al* examined longitudinal associations of changes in abdominal fat volume with incidence and changes in cardiovascular disease (CVD) risk factor profiles during a 6-year interval, suggesting that adverse changes in fat quantity are associated with changes in CVD risk factors.⁸ Hence, assessment of VAT volume change may be beneficial for monitoring CVD risks.

However, applying fat volume to clinical practice may not be feasible because of the uncertainty in its accuracy and time required to check and correct the contouring of the fatty tissue in many slices. Indeed, we found it difficult to accurately measure VAT area at the diaphragm and pelvis regions by automatic contouring. Adipose tissue around the heart near the diaphragm was mistakenly recognized as VAT, causing the VAT area calculated by automatic contouring to be larger than that calculated by manual contouring. In contrast, VAT area at the pelvis tended to be underestimated by automatic contouring.

The purpose of this study was therefore to determine the single CT slice location where VAT area best reflects changes in VAT volume and body weight. We found that the transverse correlation between

Figure 6. Correlation of interval changes between VAT area and volume. VAT, visceral adipose tissue.

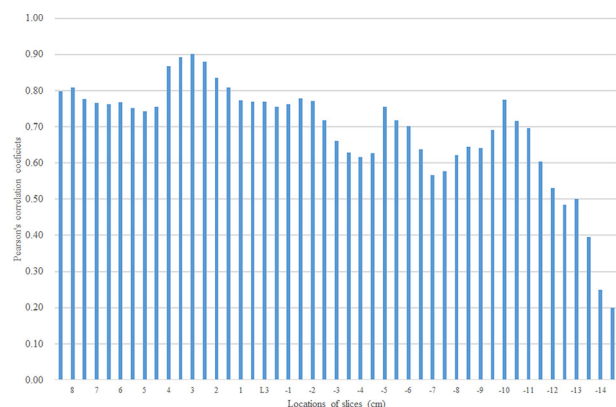
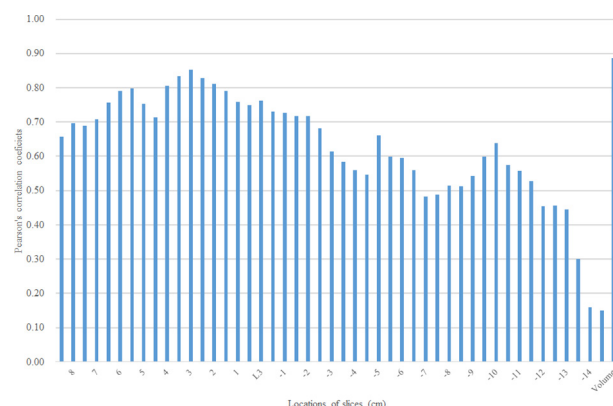


Figure 7. Correlation of interval changes between VAT area and body weight, and interval changes between VAT volume and body weight.



VAT area and volume was excellent almost throughout the slices of the abdomen and pelvis. However, only the VAT area at the slice 3 cm above the lower margin of L3 reflected interval changes in both VAT volume and body weight.

Our results concerning the transverse correlation between VAT area and volume were in good agreement with previous studies. In a community-based sample study, Irlbeck *et al* reported that measurements obtained at the umbilicus and the lower margin of L1, L2, L3, L4 and L5 were highly correlated with VAT volumes, while VAT area measured at the lower margin of L3 provided the best proxy of VAT burden for both sexes and different ages.¹⁰ Our study is unique because we determined the CT slice location where VAT area best reflects changes in VAT volume and body weight. Moreover, our results went against previous results derived from transverse analysis; VAT area measured at 3 cm above the lower margin of L3 provided the best proxy of VAT burden rather than that at the lower margin of L3.¹⁰

Table 1. Correlation coefficients between VAT area at representative slice locations and VAT volume, interval changes between VAT area at representative slice locations and VAT volume and interval changes between VAT area at representative slice locations and body weight

Pearson's correlation coefficient			
Location of slice (cm)	VAT area and volume	Interval change of VAT area and volume	Interval change of VAT area and body weight
4 cm above L3*	0.980	0.868	0.806
3 cm above L3*	0.979	0.902	0.853
L3*	0.973	0.770	0.762
Umbilicus	0.893	0.529	0.490

VAT, visceral adipose tissue; L3*, lower margin of L3.

In this study, VAT was measured by applying predefined image display settings (window range: -190/-30 HU) according to a previous study.¹¹ Although CT has emerged as the modality of choice to assess VAT volume on consecutive axial slices of the abdomen,^{17,18} various CT criteria have been applied for VAT measurement: -190/-30 HU,¹¹ -200/-10 HU,¹⁹ -200/-20 HU,²⁰ -250/-50 HU,²¹ -195/-45 HU.²² An appropriate range of CT values for adipose tissue segmentation has not yet been determined.

Several limitations to this study must be mentioned. The study population was limited to males and consisted of a relatively small sample size. In addition, because we did not perform interscan reproducibility, the values of the CT change during follow-up may have been affected by interscan variability.

In conclusion, as VAT area at a CT slice 3 cm above the lower margin of L3 can best reflect interval changes in VAT volume and body weight, VAT area measurement should be selected at this slice.

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