Dose Reduction in CT for Measurement of the Visceral Adipose Tissue: Comparison of Model-Based Iterative Reconstruction, Adaptive Statistical Iterative Reconstruction, and Filtered Back Projection Reconstruction

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Aims and objectives

Body fat tissue is traditionally distributed in two main compartments with different metabolic characteristics: the visceral adipose tissue and subcutaneous adipose tissue. Several studies have implicated abdominal visceral adipose tissue in the development of various metabolic abnormalities [1], coronary artery disease [2, 3], and cancers of the colon [4], breast [5] and prostate [6], and associations between abdominal visceral adipose tissue and coronary artery calcium score [7], systemic markers of inflammation [8], predisposition to infections and non-infectious complications, length of hospital stay, and hospital mortality [9]. The gold standard modality for quantitative measurement of the abdominal visceral fat area is computed tomography (CT) [10, 11]. Magnetic resonance imaging (MRI) can be also used to assess abdominal fat distribution [11, 12]; however, use of MRI is limited by its poor accessibility and high cost as compared to CT [10]. Providing excellent resolution for adipose tissue, CT represents a direct method for assessing the visceral fat deposition in both adult and pediatric populations [10]. On the other hand, the exposure to ionizing radiation limits its broad application in healthy subjects, as the widespread use of CT around the world has raised concern about the increase in the risk of cancer from medical radiation exposure [13]. Since radiation-induced carcinogenesis is a stochastic effect, the risk may be expected to decrease with a decrease of the radiation dose.

Several approaches have been attempted to reduce the radiation dose to patients during CT, such as use of fixed tube current reduction, automatic exposure control, peak kilovoltage reduction, use of noise reduction filters, and a high helical pitch [14-18]; furthermore, use of the recently introduced iterative reconstruction (IR) techniques has been shown to have the potential to replace the conventionally used filtered back projection (FBP) algorithm [19-23]. To the best of our knowledge, no prospective study until date has conducted intra-individual comparisons of the visceral adipose areas measured between routine-dose CT (RDCT) and low-dose CT (LDCT) performed simultaneously using automatic exposure control and a standard tube voltage of 120 kVp. Furthermore, no studies have evaluated the effect of different reconstruction algorithms, including FBP, adaptive statistical iterative reconstruction (ASIR) (so-called hybrid IR) and model-based iterative reconstruction (MBIR) (so-called pure IR), on quantitative measurement of the visceral adipose tissue.

The purpose of this study was to evaluate the effects of radiation dose reduction and the reconstruction algorithm used (FBP, ASIR or MBIR) on the measurement of abdominal visceral fat by CT.

Methods and materials

Patients

This study was conducted with the approval of our institutional review board, and written informed consent was obtained from each of the participating patients. From April 2011 to July 2011, 63 consecutive patients referred for unenhanced abdominal CT on a specific scanner were considered for inclusion in this prospective study. Patients were excluded if they were younger than 50 years old, pregnant, potentially pregnant or lactating, or did not provide written informed consent; 4 of the 63 patients did not wish to participate in the study and refused to provide informed consent. Therefore, images from the remaining 59 patients (age range, 50-83 years; mean age, 66.5 ± 8.4 years) were included in the final analysis: the patients comprised 30 men (age range, 56-80 years; mean age, 68.7 ± 7.8 years) and 29 women (age range, 50-83 years; mean age, 64.2 ± 8.5 years). The clinical indications for abdominal CT in the subjects of this study were staging or restaging of known malignancy (n = 47), diarrhea (n = 2), back pain (n = 2), chronic abdominal pain (n = 1), and follow-up for renal or ureteral stones (n = 2), giant hepatic cyst (n = 1), gallstones (n = 1), pancreatitis (n = 1), inflammatory bowel disease (n = 1) and abdominal aortic aneurysm (n = 1). The height and weight of the patients were measured, and the body mass index (BMI) was calculated as weight (in kilograms) divided by height squared (in meters).

Imaging protocol

All unenhanced abdominal CT examinations were performed on the Discovery CT750 HD scanner (GE Healthcare, Waukesha, Wisconsin, USA). All the patients were scanned craniocaudally while they lay in the supine position. According to a previous report, as the radiation dose decreases to 1/x, the image noise increases by the square root of x [24]; thus, when the radiation dose is reduced to one-quarter, the noise may be expected to increase by the square root of 4 (i.e., 2). We used this formula to calculate the probable noise index that would result in a dose reduction of approximately 75% [25]. Our standard noise index for a slice thickness of 5 mm is 12. Therefore, we considered that theoretically, a noise index of 24 (12 x 2), would yield a dose reduction of approximately 75%. The noise index settings (12 and 24) were based on our initial experiences in the clinical setting, our phantom data, and vendor recommendations, such that dose reduction was expected without loss of diagnostic information. Two helical acquisitions were obtained for each patient with the same length of helical run and field of view, to obtain two data sets for the abdomen including the top of the diaphragm and the level of the umbilicus. The first acquisition, which was routine-dose CT (RDCT), was performed under automatic exposure control (tube current modulation) using a noise index of 12 (for a slice thickness of 5 mm) under breath hold during inspiration. The second acquisition, which was LDCT, was performed under automatic exposure control using a noise index of 24 (for a slice thickness of 5 mm) under breath hold during another inspiration. The
tube current range for the RDCT and LDCT ranged from a minimum of 10 mA to a maximum of 750 mA. Other scanning parameters were the same for both the RDCT and LDCT scanning: peak tube voltage, 120 kVp; rotation speed, 0.4 second; detector collimation, 0.625 × 64 mm; table feed, 55 mm/rotation; pitch factor, 1.375; rotation speed, 0.5 seconds; pitch factor, 1.375. Thus, we obtained two raw-data files of the same size for each patient.

Image reconstruction

The series of contiguous 5-mm-thick RDCT images were reconstructed with FBP (RDCT-FBP) using a standard kernel; these images served as the reference standard. The series of contiguous 5-mm-thick LDCT images were reconstructed using FBP (LDCT-FBP), ASIR (LDCT-ASIR) and MBIR (LDCT-MBIR) with the standard kernel. Thus, the same kernels were used for the RDCT and LDCT. We used 50% ASIR, which means that 50% of the ASIR image was blended with the FBP image, selected based on previous studies [26, 27], to obtain the LDCT-ASIR images. Finally, we obtained 236 sets of 5-mm-thick images, that is, 59 image sets each of RDCT-FBP, LDCT-FBP, LDCT-ASIR and LDCT-MBIR images Fig. 1 on page 8.

Objective measurements

Two board-certified radiologists, with 7 and 22 years of experience in interpreting abdominal CT, independently measured the visceral and subcutaneous fat (adipose) areas at the level of the umbilicus, regardless of the movement of the intestines between the RDCT and LDCT acquisitions, as described previously [3, 11, 28, 29], in LDCT-FBP, LDCT-ASIR and LDCT-MBIR image series using the body fat analysis function at an independent workstation (Advantage workstation 4.5; GE Healthcare, Waukesha, Wisconsin, USA); one of the two radiologist (with 7 years of experience in interpreting abdominal CT) measured the visceral and subcutaneous fat (adipose) areas twice to evaluate the intra-observer agreement (The time interval between the first and second measurements was 4 weeks). The same two radiologists measured the visceral and subcutaneous fat (adipose) areas at the level of umbilicus by consensus in the RDCT-FBP images, which served as the reference standard. The abdominal muscular wall separating the visceral from the subcutaneous compartment was traced manually Fig. 2 on page 8. The CT attenuation range of fat was defined from -190 to -30 Hounsfield units (HU), as described previously [4, 11, 28-30]. Furthermore, the objective image noise (i.e., standard deviation of the CT number) was measured in all the 236 image series. Two board-certified radiologists, with 7 and 22 years of experience in interpreting abdominal CT, placed, by consensus, circular or ovoid regions of interest (ROIs) in the subcutaneous fat in the anterior abdominal wall (midline), retroperitoneal fat (right side), abdominal aorta, and psoas major muscle (right side) at the level of umbilicus, and the ROI size was maintained constant, to the extent possible, at approximately 1.0 cm² at all sites. The size, shape and position of the ROIs were kept constant among the four protocols.
by applying a copy-and-paste function at the workstation. CT radiation dose descriptors were recorded for all the image data sets following completion of the CT examinations.

**Statistical analysis**

Results are expressed as mean ± standard deviation. The associations between the visceral or subcutaneous adipose (fat) areas on the RDCT-FBP images and LDCT-FBP/LDCT-ASIR/LDCT-MBIR images were analyzed by calculation of the Pearson's correlation coefficient. Bland-Altman's analysis [31] was performed to evaluate the interchangeability between the visceral or subcutaneous adipose (fat) area on the RDCT-FBP images and LDCT-FBP/LDCT-ASIR/LDCT-MBIR images. The inter- and intra-observer agreements were evaluated by measuring the intra-class correlation coefficients. The differences in the median objective image noises among the four image reconstruction protocols were tested using the Wilcoxon's signed rank sum test, and Bonferroni's correction was used for multiple comparisons. The significance level for all tests was 5% (two-sided). All data were analyzed using a commercially available software program (SPSS version 19, IBM SPSS, Armonk, New York, USA).

**Fig. 1:** 75-year-old man with a body weight of 72 kg, height of 170 cm and body mass index of 24.9 kg/m²: (upper left) RDCT-FBP image at the level of the umbilicus; (upper right) LDCT-FBP image; (lower left) LDCT-ASIR image; (lower right) LDCT-MBIR image.

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**Fig. 2:** RDCT-FBP image with the line for enclosing the fat area; this image shows the methods of measurement of the visceral and subcutaneous fat areas: the boundary of the visceral fat (adipose) area is marked with the red line and the subcutaneous fat area is the area between the red line and the yellow line. The CT attenuation range of fat was defined from -190 to -30 Hounsfield units (HU).

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Results

Patient characteristics

The mean height, weight, and BMI of the 59 patients were 161.2 ± 8.4 cm (range, 146-182 cm), 59.5 ± 11.2 kg (range, 38-91 kg), and 22.9 ± 3.6 kg/m² (range, 16.0-31.9 kg/m²), respectively.

Radiation doses

The CT dose index volume (CTDIvol) values for RDCT and LDCT were 8.56 ± 3.50 and 2.31 ± 1.18 mGy, respectively (also see Appendix for details of CTDIvol); therefore, the radiation dose in LDCT was a mean 73.0% lower than that in RDCT. The estimated effective doses in RDCT and LDCT were 0.064 ± 0.026 and 0.017 ± 0.009 mSv (for 5-mm slice thickness at the level of the umbilicus), respectively, determined based on previously reported appropriate normalized coefficients for abdominal CT (0.015 mSv/(mGy cm)) [32] and estimates of dose-length product measurements (4.28 ± 1.75 and 1.16 ± 0.59 mGy cm, respectively, for a 5-mm slice thickness).

Visceral and subcutaneous fat measurements

The measured visceral fat areas on the RDCT-FBP, LDCT-FBP, LDCT-ASIR, and LDCT-MBIR images were 120.9 ± 65.3 cm² (range, 25.2-346.9 cm²), 121.4 ± 64.2 cm² (range, 30.6-342.6 cm²), 121.3 ± 64.9 cm² (range, 27.7-344.6 cm²), 120.7 ± 65.3 cm² (range, 24.3-344.4 cm²), respectively. The measured subcutaneous fat areas on the RDCT-FBP, LDCT-FBP, LDCT-ASIR, and LDCT-MBIR images were 155.7 ± 82.8 cm² (range, 13.9-356.3 cm²), 157.3 ± 83.5 cm² (range, 14.3-356.6 cm²), 157.5 ± 83.6 cm² (range, 13.0-356.6 cm²), 155.8 ± 83.3 cm² (range, 12.4-353.9 cm²), respectively.

Excellent correlations were observed between the measured visceral fat areas on the RDCT-FBP and LDCT-FBP images (r = 0.998; P < 0.001), on the RDCT-FBP and LDCT-ASIR images (r = 0.998; P < 0.001), and on the RDCT-FBP and LDCT-MBIR images (r = 0.998; P < 0.001) Fig. 3 on page 14. Excellent correlations were also observed between the measured subcutaneous fat areas on the RDCT-FBP and LDCT-FBP images (r = 0.992; P < 0.001), on the RDCT-FBP and LDCT-ASIR images (r = 0.992; P < 0.001), and on the RDCT-FBP and LDCT-MBIR images (r = 0.992; P < 0.001).

The average differences in the measured visceral fat area, which are also an estimate of agreement, were very small between the RDCT-FBP and LDCT-FBP images (difference, -0.47 ± 3.97 cm²; 95% confidence interval [CI], -1.51 to 0.56 cm²; limits of agreement,
-8.25 to 7.31 cm$^2$), RDCT-FBP and LDCT-ASIR images (difference, -0.41 ± 3.96 cm$^2$; 95% CI, -1.44 to 0.63 cm$^2$; limits of agreement, -8.17 to 7.36 cm$^2$), and RDCT-FBP and LDCT-MBIR images (difference, 0.18 ± 3.86 cm$^2$; 95% CI, -0.83 to 1.18 cm$^2$; limits of agreement, -7.39 to 7.75 cm$^2$) Fig. 4 on page 14. However, one patient showed an approximately 20 cm$^2$ difference of the measured visceral fat area between RDCT-FBP and LDCT-FBP, LDCT-ASIR or LDCT-MBIR Fig. 4 on page 14. This was considered to be attributable to the relatively large movement of the intestines between the RDCT and LDCT acquisitions.

The average differences in the measured subcutaneous fat areas were also very small between the RDCT-FBP images and LDCT-FBP images (difference, -1.56 ± 10.77 cm$^2$; 95% CI, -4.37 to 1.25 cm$^2$; limits of agreement, -22.67 to 19.55 cm$^2$), RDCT-FBP and LDCT-ASIR images (difference, -1.78 ± 10.76 cm$^2$; 95% CI, -4.58 to 1.02 cm$^2$; limits of agreement, -22.86 to 19.30 cm$^2$), and RDCT-FBP and LDCT-MBIR images (difference, -0.08 ± 10.62 cm$^2$; 95% CI, -2.85 to 2.68 cm$^2$; limits of agreement, -20.89 to 20.73 cm$^2$).

The intra-observer agreements (intra-class correlation coefficients) were #0.975 and the inter-observer agreements (intra-class correlation coefficients) between the two radiologists were #0.980, as summarized in Table 1.

**Table 1:** Intra-observer and inter-observer agreements (intra-class correlation coefficients [ICC]) for the LDCT-FBP, LDCT-ASIR, and LDCT-MBIR images

<table>
<thead>
<tr>
<th></th>
<th>LDCT-FBP</th>
<th>LDCT-ASIR</th>
<th>LDCT-MBIR</th>
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<tr>
<td><strong>Intra-observer agreements</strong></td>
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<td>(ICCs) for the visceral fat area</td>
<td>0.995 (0.991-0.997)</td>
<td>0.995 (0.992-0.997)</td>
<td>0.995 (0.992-0.997)</td>
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<td><strong>Intra-observer agreements</strong></td>
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<tr>
<td>(ICCs) for the subcutaneous fat area</td>
<td>0.975 (0.959-0.985)</td>
<td>0.982 (0.970-0.989)</td>
<td>0.983 (0.972-0.990)</td>
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<td><strong>Inter-observer agreements</strong></td>
<td>0.986</td>
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Objective image noise

The LDCT-MBIR images showed significantly reduced objective image noise in all the ROIs \((P < 0.0001)\) as compared to the RDCT-FBP, LDCT-FBP and LDCT-ASIR images (Table 2). As compared to the RDCT-FBP images, the LDCT-FBP and LDCT-ASIR images showed significantly increased objective image noise in all the ROIs \((P < 0.0001)\) (Table 2).

**Table 2: Objective image noise in the RDCT-FBP, LDCT-FBP, LDCT-ASIR, and LDCT-MBIR images**

<table>
<thead>
<tr>
<th>Protocol</th>
<th>RDCT-FBP</th>
<th>LDCT-FBP</th>
<th>LDCT-ASIR</th>
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<tr>
<td>Image noise (HU)</td>
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<td>Retroperitoneal fat</td>
<td>14.0 ± 2.2</td>
<td>25.8 ± 3.7</td>
<td>18.5 ± 2.7</td>
<td>8.9 ± 1.7</td>
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<td>Subcutaneous fat</td>
<td>10.2 ± 1.7</td>
<td>17.3 ± 2.2</td>
<td>12.5 ± 1.8</td>
<td>7.9 ± 1.6</td>
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<td>Abdominal aorta</td>
<td>14.5 ± 4.2</td>
<td>26.4 ± 3.4</td>
<td>18.3 ± 2.7</td>
<td>9.3 ± 2.5</td>
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<tr>
<td>Psoas major muscle</td>
<td>15.0 ± 2.0</td>
<td>28.9 ± 3.7</td>
<td>20.3 ± 2.5</td>
<td>8.4 ± 1.1</td>
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<td>RDCT-FBP and LDCT-FBP</td>
<td>RDCT-FBP and LDCT-ASIR</td>
<td>RDCT-FBP and LDCT-MBIR</td>
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**Pair-wise comparison; *P*-value**

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*Wilcoxon's signed rank sum test.

*P* < 0.0083 was considered to be statistically significant with Bonferroni correction for multiple comparisons.

*: Statistically significant (*P* < 0.0083)

HU indicates Hounsfield units.

Images for this section:

Fig. 3: (Upper left) association between the visceral fat areas measured on the LDCT-FBP and RDCT-FBP (reference standard) images. (Upper right) association between the measured visceral fat areas on the LDCT-ASIR and RDCT-FBP images. (Lower left) association between the measured visceral fat areas on the LDCT-MBIR and RDCT-FBP images. Scatter-plots in (upper left), (upper right), and (lower left) show excellent correlations (all P < 0.001).

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Fig. 4: Bland-Altman plots: (Upper left) differences in the measured visceral fat areas between RDCT-FBP and LDCT-FBP images; (Upper right) differences in the measured visceral fat areas between RDCT-FBP and LDCT-ASIR images; (Lower left) differences in the measured visceral fat areas between RDCT-FBP and LDCT-MBIR images. The outer dotted lines delineate the limits of agreement between the two images.

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Conclusion

Our prospective study showed that the visceral and subcutaneous fat areas measured on the LDCT-FBP, LDCT-ASIR and LDCT-MBIR images were almost equal to those measured on the RDCT-FBP images. Considering our results, it appears that quantitative CT assessment of visceral adipose tissue, which is important for evaluating the potential risk of development of many diseases such as metabolic syndrome, cardiovascular diseases and various malignancies [1-7], as well as for an accurate estimation of the prognosis, would be possible at a radiation dose approximately one-fourth of that in RDCT. The estimated effective dose in LDCT for the measurement of visceral fat in this study was 0.017 ± 0.009 mSv, which is comparable to the radiation dose that a patient is exposed to during a plain abdominal radiograph. Therefore, in terms of the radiation dose, the LDCT protocol in this study for measurement of visceral fat could be applied also to healthy subjects for assessment of the potential risk of various pathologies or accurate estimation of the prognosis.

With regard to lowering the dose of CT for measuring the visceral adipose tissue, a previous study compared the 90-kVp (CTDlvol, 5.0 ± 0.1 mGy) protocol with the 140-kVp protocol (CTDlvol, 18.8 ± 0.2 mGy) [33]; however, the different kVp settings resulted in heterogeneous values for the CT numbers of fat, which could have introduced bias in their results. In this study, we used only the conventional 120-kVp setting to avoid the bias caused by different kVp settings. Furthermore, the CTDlvol in our LDCT protocol (2.3 ± 1.2 mGy) was lower than that in the previously reported 90-kVp protocol (CTDlvol, 5.0 ± 0.1 mGy).

FBP uses ideal system optics, such as a point x-ray source, a pencil x-ray beam and point of detector elements. These simplified mathematical assumptions allow very fast image reconstruction, which was an important consideration in the early days of CT [23]. ASIR introduced system statistics into conventional FBP, conferring image noise and/or radiation dose reduction capabilities [19, 25, 34]. MBIR has been developed to overcome the limitation in relation to dose reduction capability and a trade-off between spatial resolution and image noise. The major difference between MBIR and ASIR is that MBIR uses a full system optics model and full system statistical model [35-37], and calculation for each voxel is conducted one by one through a full iterative reconstruction process between the projection space and image space [23]. This allows improved image quality with a higher spatial resolution and much lower image noise and/or lower radiation dose to be realized, as compared with that obtained using FBP and ASIR. Our study showed the lowest objective image noise in the LDCT-MBIR images among the 4 image protocols and lower objective noise in the LDCT-ASIR images as compared to that in the LDCT-FBP images. Although our results are consistent with previous reports on the image noise [19, 22, 23], we found that application of IR did not affect the quantitative values of the visceral or subcutaneous fat area in the LDCT as compared to the RDCT.
images. MBIR currently requires between 30 to 60 minutes for reconstruction of the images of a single patient, which would limit its application in routine CT examination [23]. Considering our results, FBP or ASIR (reconstruction time per patient, under 1-2 minutes) may be sufficient for reconstructing LDCT images for the measurement of visceral fat. With regard to the quantitative measurements, previous studies have demonstrated that iterative reconstruction algorithms can affect quantitative measurements of the lung and airways [38] as well as the coronary artery calcium scoring [39].

Our study had several limitations. First, we included only 59 patients, and further studies on larger patient populations are required to confirm these preliminary findings. Second, the average BMI of the patients in this study was 22.9 kg/m$^2$, and a future study may be needed to confirm the results for more obese patients. Third, we only compared the routine dose with one-fourth of the routine dose. Further studies comparing RDCT with CT using less than one-fourth of the routine dose may be desirable, although we believe that the radiation dose in our LDCT protocol was sufficiently low. LDCT acquired at less than one-fourth of the routine dose may affect the quantitative measurements of visceral or subcutaneous fat, and application of IR techniques may also affect these values.

In conclusion, a 73.0% reduction of the radiation dose would be possible in CT for measurement of the abdominal visceral fat, regardless of the reconstruction algorithm used, namely FBP, hybrid IR or pure IR.

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