Prediction of total subcutaneous abdominal, intraperitoneal, and retroperitoneal adipose tissue masses in men by a single axial magnetic resonance imaging slice

Nicola Abate, Abhimanyu Garg, Ryan Coleman, Scott M Grundy, and Ronald M Peshock

ABSTRACT
To develop a simplified but accurate method for determining the masses of various abdominal adipose tissue compartments, we studied the predictive value of masses of intraperitoneal, retroperitoneal, and subcutaneous abdominal adipose tissue determined on single axial abdominal magnetic resonance imaging (MRI) slices taken at various intervertebral levels from the 12th thoracic to 1st sacral vertebra (identified on a sagittal section) for the respective total masses of each compartment calculated from contiguous 10-mm thick MRI slices covering the entire abdomen in 49 men (26 without diabetes and 23 with non-insulin-dependent diabetes mellitus). The MRI slice at the intervertebral level between the lumbar (L) 2 and 3 vertebrae showed the highest and most consistent predictive value for all three compartments ($R^2 = 0.85$ for all). Furthermore, compared with other intervertebral levels, the L2-L3 level had a higher amount of intraperitoneal and retroperitoneal adipose tissue mass. We conclude that determining the masses of various abdominal adipose tissue compartments at the L2-L3 intervertebral level by MRI is an acceptably reliable and accurate method for studying abdominal adiposity in men. Am J Clin Nutr 1997;65:403-8.

KEY WORDS Magnetic resonance imaging, obesity, intraperitoneal fat, retroperitoneal fat, subcutaneous fat

INTRODUCTION
We reported recently a method using magnetic resonance imaging (MRI) to precisely measure masses of various abdominal adipose tissue compartments, i.e., intraperitoneal, retroperitoneal, and subcutaneous (1). This method used MRI scanning of the entire abdomen and integration of data from multiple contiguous slices. We then used this technique to define the relations between body fat distribution and insulin sensitivity in nondiabetic healthy men and in patients with non-insulin-dependent diabetes mellitus (NIDDM) (2, 3). The cost, however, of obtaining contiguous transverse-axial MRI slices covering the entire abdomen and the time involved in determining the actual masses of various abdominal fat compartments precludes its application to a large number of individuals. There is a need, therefore, to develop a simplified but accurate method for determining abdominal fat distribution that can be used in epidemiologic as well as metabolic studies.

Thus, the current investigation was carried out to study the predictive value of masses of various adipose tissue compartments computed from single axial abdominal MRI slices at various intervertebral levels for the respective total masses of each compartment calculated from contiguous slices covering the entire abdomen. The primary aim was to select the single best abdominal MRI slice having the highest predictive value for the total integrated masses. Another aim was to study amounts of subcutaneous abdominal, intraperitoneal, and retroperitoneal adipose tissue at various intervertebral levels from the 12th thoracic (T) to 1st sacral (S) vertebra.

SUBJECTS AND METHODS
Subjects
The current investigation included 49 men (26 nondiabetic healthy subjects: 18 white, 4 African-American, 1 Hispanic, and 3 Asian; and 23 patients with NIDDM: 12 white, 1 African-American, 9 Hispanic, and 1 Asian) who had MRI studies of the abdominal region and also had sagittal sections available. Nondiabetic status was determined by a standard oral-glucose-tolerance test (2, 3). Exclusion criteria included other endocrine disorders, coronary artery disease, abnormal liver or renal function tests, and any drug therapy. The study was approved by the Institutional Review Board of the University of Texas Southwestern Medical Center; all subjects gave informed written consent before participating. A medical history was obtained and a physical examination was conducted, followed by screening for hematologic and blood chemistry abnormalities of the subjects. Their mean (± SD) age was 51.2 ± 9.7 y with a range from 35 to 73 y, and mean body mass index (BMI; kg/m$^2$) was 28.2 ± 6.5 with a range from 21.0

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3 Address reprint requests to A Garg, Department of Internal Medicine, Center for Human Nutrition, 5323 Harry Hines Boulevard, Dallas, TX 75235-9052. E-mail: garg@crdec.swmed.edu.

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to 46.4. The total body fat content studied by hydrodensitometry (2) ranged from 12.3% to 43.4% of the total body mass.

**MRI**

The MRI studies were performed by using a 0.35-T imaging device (Toshiba America MRI, Inc, San Francisco) with a quadrature body coil as described previously (1, 2). The entire abdominal region was scanned by using contiguous 10-mm transaxial slices. The total masses of subcutaneous abdominal, intraperitoneal, and retroperitoneal adipose tissue compartments were determined as described earlier by assuming the density of adipose tissue to be 0.9196 kg/L (1, 2).

For each subject, axial images at various intervertebral levels, including, T12-lumbar (L) 1, L1-L2, L2-L3, L3-L4, L4-L5, and L5-S1, were identified first on a sagittal section. The data for subcutaneous abdominal, intraperitoneal, and retroperitoneal adipose tissue masses from these intervertebral levels were identified from the entire study for each subject.

**Calculations and statistical analyses**

Pearson product-moment correlation coefficients (r) were computed for all subjects and for nondiabetic and NIDDM groups separately, to assess the association between masses of adipose tissue compartments of each MRI slice and the total adipose tissue mass of the corresponding compartment. The correlation coefficients for the two groups were similar at each intervertebral level (data not shown). Furthermore, in the multiple-regression models, the grouping factor (no diabetes or NIDDM) had no predictive value (explained < 1% of the variability for total adipose tissue masses). The data of the two groups, therefore, were combined for regression models and are presented together. Multiple-regression models were used to determine the amount of variability explained (R²) by each slice or combinations of slices in predicting total adipose tissue mass for each compartment (4).

For each compartment, ie, subcutaneous, intraperitoneal, and retroperitoneal, a repeated-measures analysis of variance model (using log-transformed data because of skewness) was used to compare the fat mass between the various intervertebral levels (slice) and to assess differences between nondiabetic and NIDDM subjects. The group × slice interaction was not significant for all compartments, but approached significance for intraperitoneal fat mass (P < 0.1). However, comparison of intraperitoneal fat mass at each intervertebral level between the nondiabetic and NIDDM subjects revealed no significant differences (P > 0.2). Therefore, the data for all subjects were combined and paired t tests were used to assess differences in subcutaneous, intraperitoneal, and retroperitoneal adipose tissue mass at different intervertebral levels. The significance level was adjusted for multiple comparisons and the 0.01 level of significance was used. Statistical analysis was performed by using BMDP statistical software (SPSS Inc, Chicago).

**RESULTS**

The distribution of subcutaneous abdominal, intraperitoneal, and retroperitoneal fat masses as calculated in the MRI slices taken at different intervertebral levels from T12-L1 to L5-S1 is shown in *Figure 1*. The subcutaneous abdominal fat mass at the T12-L1 and L1-L2 levels was similar, however, it progressively increased in the caudal sections and at each level was different from those at other levels (P < 0.01). The subcutaneous abdominal fat masses at the L4-L5 and L5-S1 levels, however, were not significantly different (P = 0.5). The distribution of intraperitoneal and retroperitoneal fat was markedly different from that of subcutaneous abdominal fat. The maximum amount of intraperitoneal and retroperitoneal fat was located at the L2-L3 intervertebral level. The intraperitoneal fat mass at the L2-L3 level was significantly greater than the corresponding fat masses at all other levels (P < 0.01) except that at the L3-L4 level (P = 0.12). The retroperitoneal fat mass at the L2-L3 level was also significantly higher than the corresponding fat masses at the T12-L1, L1-L2, and L5-S1 levels.

**TABLE 1**

<table>
<thead>
<tr>
<th>MRI slice level</th>
<th>SC-SC fat</th>
<th>IP-IP fat</th>
<th>RP-RP fat</th>
</tr>
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<tbody>
<tr>
<td>T12-L1 (n = 43)</td>
<td>0.93</td>
<td>0.83</td>
<td>0.40</td>
</tr>
<tr>
<td>L1-L2 (n = 49)</td>
<td>0.94</td>
<td>0.89</td>
<td>0.75</td>
</tr>
<tr>
<td>L2-L3 (n = 49)</td>
<td>0.92</td>
<td>0.92</td>
<td>0.92</td>
</tr>
<tr>
<td>L3-L4 (n = 49)</td>
<td>0.89</td>
<td>0.93</td>
<td>0.90</td>
</tr>
<tr>
<td>L4-L5 (n = 45)</td>
<td>0.87</td>
<td>0.87</td>
<td>0.80</td>
</tr>
<tr>
<td>L5-S1 (n = 21)</td>
<td>0.96</td>
<td>0.86</td>
<td>0.75</td>
</tr>
</tbody>
</table>

*Pearson’s correlation coefficients. T, thoracic vertebra; L, lumbar vertebra; and S, sacral vertebra.*
FIGURE 2. A: Relation of subcutaneous abdominal fat mass at the L2-L3 intervertebral disc level and total subcutaneous abdominal fat mass in 49 men (●, 23 with non-insulin-dependent diabetes mellitus; and ○, 26 nondiabetic subjects). The best-fit regression line is represented by a solid line and 95% CI for the data by interrupted lines. \( y = 0.427 + 21x; R^2 = 0.85, P < 0.001 \). B: The differences between the observed and predicted masses of total subcutaneous abdominal fat mass at each level of observed total subcutaneous abdominal fat mass. The solid line denotes no differences and interrupted lines, 2 SD for the data.

\( (P < 0.01) \), but was not significantly different from those at the L3-L4 \( (P = 0.12) \) and L4-L5 levels \( (P = 0.03) \).

The correlation coefficients between masses of subcutaneous abdominal, intraperitoneal, and retroperitoneal fat calculated at single MRI slices at different intervertebral levels and the corresponding total subcutaneous abdominal, intraperitoneal, and retroperitoneal fat masses computed from the entire abdominal study are shown in Table 1. In general, all the single MRI slices showed a high predictive value for the total subcutaneous abdominal fat mass \( (r = 0.87-0.96 \text{ and } R^2 = 0.76-0.92) \). Therefore, the decision to select the single best MRI slice was mainly based on the predictive values for the total intraperitoneal and retroperitoneal fat masses. Of all the transverse-axial MRI slices at intervertebral locations, the slice at the L2-L3 level showed the highest and most consistent predictive value for total intraperitoneal and retroperitoneal fat masses \( (R^2 = 0.85 \text{ for both}) \).

The relations of fat masses of subcutaneous abdominal, intraperitoneal, and retroperitoneal compartments at the L2-L3 MRI slice with the corresponding total subcutaneous abdominal, intraperitoneal, and retroperitoneal fat masses, respectively, are shown in Figures 2, 3, and 4, respectively. Equations for predicting total masses of each compartment from the data obtained from the L2-L3 MRI slice are as follows:

- Total subcutaneous abdominal adipose tissue mass (kg)
  \[ = 0.427 + 21 \times \text{subcutaneous abdominal adipose tissue mass at L2–L3} \]
- Total intraperitoneal adipose tissue mass (kg)
  \[ = 0.181 + 16 \times \text{intraperitoneal adipose tissue mass at L2–L3} \]
- Total retroperitoneal adipose tissue mass (kg)
  \[ = 0.256 + 13 \times \text{retroperitoneal adipose tissue mass at L2–L3} \]

By using these equations, the differences between observed and predicted values of the total subcutaneous, intraperitoneal, and retroperitoneal compartments were calculated for each subject and were plotted against the observed masses of the respective compartment in Figures 2, 3, and 4, respectively, to

FIGURE 3. A: Relation of intraperitoneal fat mass at the L2-L3 intervertebral disc level and total intraperitoneal fat mass in 49 men (●, 23 with non-insulin-dependent diabetes mellitus; and ○, 26 nondiabetic subjects). The best-fit regression line is represented by a solid line and 95% CI for the data by interrupted lines. \( y = 0.181 + 16x; R^2 = 0.85, P < 0.001 \). B: The differences between the observed and predicted masses of intraperitoneal fat mass at each level of observed total intraperitoneal fat mass. The solid line denotes no differences and interrupted lines, 2 SD for the data.
suggest variability at different levels of regional adiposity.

Further, multiple-regression models were used to determine whether a combination of information from the L2-L3 slice with that from adjacent intervertebral slices would increase the amount of variability explained ($R^2$) by the L2-L3 slice in predicting total adipose tissue mass for each compartment (Table 2). Combinations of the L2-L3 slice with either the L1-L2 or L3-L4 slice did not result in consistent increases in predictability; however, a combination of three slices, i.e., the L1-L2, L2-L3, and L3-L4 slices, raised the predictability for each compartment significantly to ~90-91%.

**DISCUSSION**

A prerequisite for conducting the present study was to have an accurate method to measure total masses of various abdominal compartments. To accomplish this, we validated recently an MRI-based method for integrating data from multiple contiguous slices covering the entire abdomen (1). MRI data were validated by comparing them with actual amounts of fat in different compartments by dissection in cadavers. This MRI method can precisely measure subcutaneous abdominal, intraperitoneal, and retroperitoneal adipose tissue masses in single slices and also in the entire abdomen. We, thus, have a unique opportunity to systematically study the predictive value of masses of subcutaneous abdominal, intraperitoneal, and retroperitoneal compartments calculated from single transaxial images at various intervertebral levels for the total mass of the corresponding compartments.

The previous computerized tomography or MRI studies investigating the predictive value of subcutaneous abdominal or visceral adipose tissue areas from single slices for the corresponding adipose tissue area or volume estimated from multiple slices are reviewed in Table 3 (5–9). These studies, however, had several limitations that were addressed in our study. Of particular note in the previous studies, no distinction was made between the intraperitoneal and retroperitoneal fat. Although we reported recently that subcutaneous abdominal or truncal fat had the most predictability for insulin sensitivity (2, 3), there is a possibility that intraperitoneal fat, which drains into the portal circulation, may have unique effects on hepatic intermediary metabolism. It seems, therefore, necessary to first delineate it from retroperitoneal fat in evaluating the consequences of excess intraabdominal fat. Second, all previous studies reported on relations of adipose tissue areas from a single slice to average adipose tissue area or volume estimated from multiple slices. In our protocol, masses of the three adipose tissue compartments from single, 10-mm thick slices were correlated to the respective total masses of these compartments. Thickness of the MRI slices was taken into consideration in calculating adipose tissue volume in our study. Third, subcutaneous abdominal or visceral adipose tissue volumes in the previous studies were estimated by assuming truncated pyramidal, conical, or cylindrical geometric configurations between pairs of consecutive slices; these estimated volumes may not be accurate. In our study, volumes of subcutaneous abdominal, intraperitoneal, and retroperitoneal adipose tissue compartments were calculated by mapping these regions on contiguous MRI slices of 10-mm thickness covering the entire abdomen, and therefore, no geometrical assumptions were made. The actual masses of different adipose tissue compartments were then calculated from the respective volumes. Fourth, in previous studies using computerized tomography, slices were obtained at approximate levels, e.g., at the L2-L3 vertebra. In the current investigation, sagittal sections

**TABLE 2**

Predictive value ($R^2$) of subcutaneous abdominal (SC), intraperitoneal (IP), and retroperitoneal (RP) fat masses from magnetic resonance imaging (MRI) slice at lumbar (L) intervertebral disc level 2–3 either alone or in combination with masses from other adjacent intervertebral slices for the corresponding total SC, IP, and RP fat masses, respectively

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>L2-L3 (n = 49)</td>
<td>0.85</td>
<td>0.85</td>
<td>0.85</td>
</tr>
<tr>
<td>L1-L2, L2-L3 (n = 49)</td>
<td>0.90†</td>
<td>0.89†</td>
<td>0.85</td>
</tr>
<tr>
<td>L2-L3, L3-L4 (n = 49)</td>
<td>0.85</td>
<td>0.88‡</td>
<td>0.91‡</td>
</tr>
<tr>
<td>L1-L2, L2-L3, L3-L4 (n = 49)</td>
<td>0.90†</td>
<td>0.91†</td>
<td>0.91†</td>
</tr>
<tr>
<td>L2-L3, L3-L4, L4-L5 (n = 45)</td>
<td>0.86</td>
<td>0.88‡</td>
<td>0.94‡</td>
</tr>
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</table>

† $P < 0.05$ for increase in $R^2$ above that for the L2-L3 slice.
were obtained in each individual to precisely identify various intervertebral levels.

Although several investigators have empirically obtained single slices by computerized tomography or MRI at the level of the umbilicus (10–13), L4 vertebra, or L4-L5 intervertebral disc (14–16), the results of our study indicate that the intervertebral disc level between the L2 and L3 vertebrae has the most consistent and strongest predictive ability for the total mass of all three abdominal compartments compared with other intervertebral levels. Retroperitoneal fat mass is the smallest of the three compartments (1–3), and probably because of this, a large variation was noted in predictability of various intervertebral slices for the total retroperitoneal fat mass. The L2-L3 level showed the maximum predictive ability for the total retroperitoneal fat mass.

Furthermore, the amount of intraperitoneal and retroperitoneal fat at the L2-L3 level was higher than that at any other intervertebral levels except the L3-L4. This provides additional support for using the L2-L3 level as the single best slice for studying intraabdominal obesity. In a recent study by Ross et al (17), the largest mean values for intraabdominal adipose tissue areas were obtained on the images 10 and 15 cm above the L4-L5 level in men and at 5 and 10 cm above the L4-L5 level in women. In fact, the L2-L3 level corresponds roughly to the level 10 cm above the L4-L5 level and, thus, the findings of Ross et al (17) support our observations of the maximum amount of intraperitoneal and retroperitoneal fat at the L2-L3 level. Perirenal fat constitutes a major portion of the retroperitoneal fat compartment and a better delineation of perirenal fat on both sides at the L2-L3 level may be another reason that this level is the best for studying regional abdominal adiposity in men. It is possible that the L2-L3 level may also be the best for studying abdominal obesity in women, but this remains to be studied.

Combining information obtained from the L2-L3 slice with that from an adjacent intervertebral slice did not result in a consistent increase in predictability for the total masses of abdominal compartments. However, a combination of the L1-L2, L2-L3, and L3-L4 slices consistently raised the predictability from 85% (for L2-L3 alone) to ~90%. Therefore, for studies requiring higher precision, a combination of these three slices could be used.

Finally, we conclude that determining the masses of subcutaneous, intraperitoneal, and retroperitoneal adipose tissue on a single transaxial MRI slice at the level of the L2-L3 intervertebral disc has a high degree of predictability for the total subcutaneous abdominal, intraperitoneal, and retroperitoneal masses. This method provides a simple and less expensive solution to address questions about the role of distribution of abdominal fat.

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REFERENCES