# Estimation of adipose tissue mass by magnetic resonance imaging: validation against dissection in human cadavers[1]

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**Abstract** The evaluation of adipose tissue distribution has become an essential component of investigations on the complications of obesity. However, a major limitation is lack of methodology for accurate estimation of adipose tissue mass in the different regions of the body. Therefore, we have tested the accuracy and precision of magnetic resonance imaging (MRI) as a method to measure adipose tissue mass in regions of the body not accessible with standard anthropometric methods. The mass of subcutaneous and intraabdominal adipose tissue estimated by MRI was compared with that obtained by direct weighing of the same adipose tissue compartments after dissection in human cadavers. MRI was performed on three unembalmed cadavers (two males, one female) who were subsequently dissected to isolate intraperitoneal, retroperitoneal, and subcutaneous adipose tissues. These same components were delineated by MRI. The results of the two methods were highly congruent. For the various compartments, the mean of the difference between the two methods was only 0.076 kg (95% confidence interval + 0.005 kg and + 0.147 kg). The "limits of agreement" between the two techniques were −0.066 kg and +0.218 kg. Multiple repeated estimates of mass of adipose tissue compartments were made to determine reproducibility of the MRI measurement; the coefficient of variation for repeated measures was below 14%. The results of this study show that MRI is an accurate and precise technique to evaluate adipose tissue mass in subcutaneous and intraabdominal compartments. Furthermore, MRI was found to be a valid method to separately evaluate the mass of intraabdominal subcompartments of intraperitoneal and retroperitoneal adipose tissue.—**Abate, N., D. Burns, R. M. Peshock, A. Garg, and S. M. Grundy.** Estimation of adipose tissue mass by magnetic resonance imaging: validation against dissection in human cadavers. *J. Lipid Res.* 1994. **35:** 1490-1496.

**Supplementary key words** body mass index • intraperitoneal adipose tissue • retroperitoneal adipose tissue • subcutaneous adipose tissue

There is growing evidence that the distribution of body fat influences the metabolic consequences of obesity. Specifically, the accumulation of body fat in the abdominal area has been reported to accentuate the hyperinsulinemia, dyslipidemia, and hypertension commonly associated with obesity (1-6). However, all investigators are not in uniform agreement that abdominal obesity has a more detrimental effect on these metabolic abnormalities than the same amount of excess fat in other body locations. Much of this uncertainty derives from the lack of methodology for accurate determination of adipose tissue mass in the different regions of the body. The measurement of abdominal fat is particularly difficult. Whereas quantities of subcutaneous adipose tissue can be determined with reasonable accuracy by techniques such as ultrasound or measurement of skin-fold thickness by caliper (7-11), internal adipose tissue compartments are difficult to measure accurately.

Advances in imaging techniques, e.g., computerized tomography (CT) (9, 12-20) and magnetic resonance imaging (MRI) (21-26) offer new promise for the visualization and quantification of adipose tissue masses in different compartments. MRI is particularly promising because of its lack of radiation exposure and its superior imaging of adipose tissue. The adipose tissue of various body compartments can be readily identified by MRI because fat has a different proton relaxation time as compared to other tissue constituents (26). Nonetheless, systematic studies of the validity of MRI as a method to measure adipose tissue mass are lacking. In the current study, an attempt was made to validate the use of MRI in estimating abdominal adipose tissue mass by comparing results to direct measurement of adipose tissue mass after dissection of human cadavers.

Abbreviations: CT, computerized tomography; MRI, magnetic resonance imaging; BMI, body mass index.

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TABLE 1. General characteristics of the subjects studied

| | Subject 1 | Subject 2 | Subject 3 |
|---|---|---|---|
| Age (yr) | 54 | 57 | 69 |
| Sex | male | male | female |
| Body mass index (kg/m²) | 27 | 31 | 23 |
| Cause of death | gastric cancer | brain cancer | liver cancer |

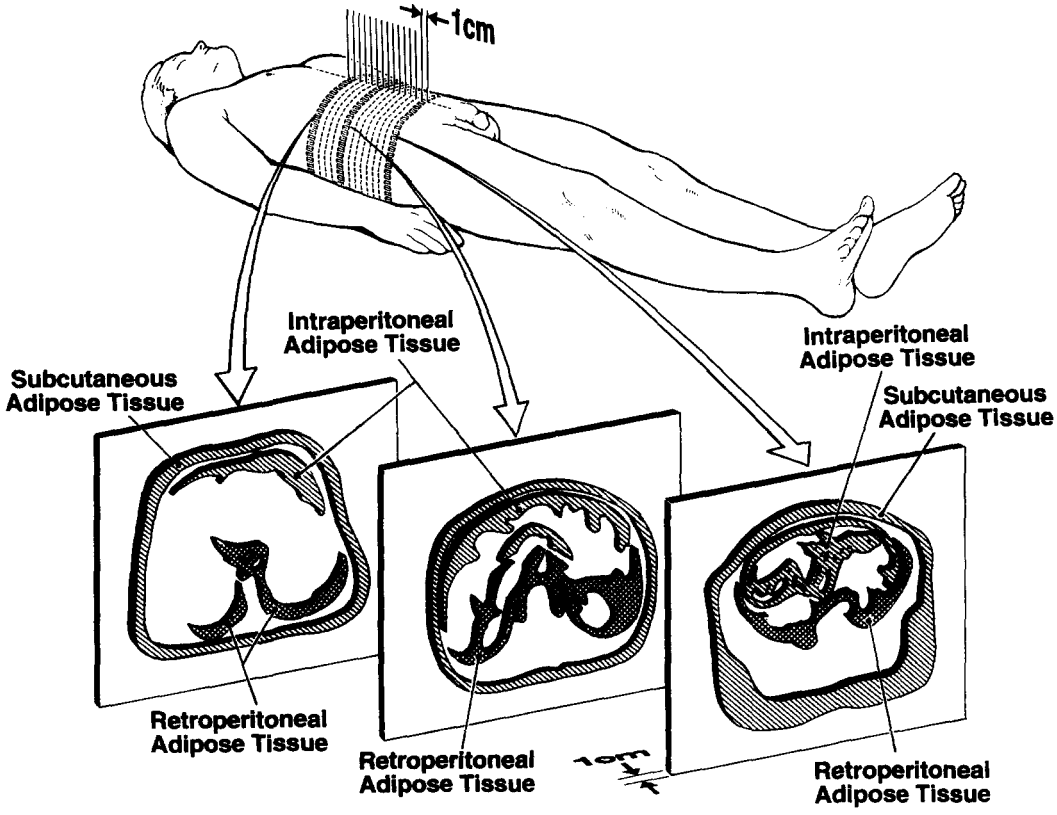
## SUBJECTS AND METHODS

### Subjects

Three unembalmed cadavers (two males and one female) were supplied by the Department of Anatomy of the University of Texas Southwestern Medical Center at Dallas. They had been obtained within a few hours of death and were stored at 4°C. All were studied within 7 days of death. The general characteristics of the three bodies studied are presented in **Table 1.** Weights and heights were determined immediately after death at the time the bodies were obtained by the Department of Anatomy. Body mass indexes (BMI) in kg/m² were calculated by these measurements. The three cadavers were chosen to have a broad range of BMI, to evaluate MRI accuracy at different levels of adipose tissue mass. The causes of death were gastric cancer, brain cancer, and liver cancer (subjects 1, 2, and 3, respectively). No gross intraabdominal metastatic lesions were observed in any of the three subjects. Some ascitic fluid was found in subject 3 on dissection.

### Magnetic resonance imaging

The bodies were transported to the Radiology Department where MRI studies were performed. The instrument used was a 0.35 Tesla imaging device (Toshiba America MRI, Inc., South San Francisco, CA) with a quadrature body coil. The bodies were positioned in the magnet in a supine position, arms placed laterally. As shown in a schematic representation in **Fig. 1,** the entire abdominal region was scanned using contiguous axial 10 mm slices. The MRI studies used a T(Tau)1-weighted spin echo sequence with 300-milliseconds repetition time and 15-milliseconds echo time, one-half excitation for all




1. Schematic illustration of the abdominal MRI study. A series of contiguous axial 10 mm slices were employed to scan the entire abdomen.

acquisitions. Seven slices were obtained for each acquisition sequence. The duration of each acquisition of seven slices was 36 seconds. Three to four acquisition sequences were necessary to cover the entire abdomen. All images were acquired on a 256 × 192 matrix within a 51.2 × 38.4 cm field of view, 2 ×2 × 10 $mm^3$ voxel, giving a 40 $mm^3$ pixel volume. All images data were stored on magnetic tapes and transferred to a Toshiba 0.35 Computer (Toshiba Inc., South San Francisco, CA) for analysis.

As evident in **Figure 2,** adipose tissue areas were easily identified on the images because fat has short T1 and long T2 proton relaxation times as compared to other tissues. Many pathological processes may result in prolongation of both T1 and T2 times. However, the short T1 time of fat is characteristic, and it results in high signal intensity (increased brightness) on T1-weighted images. The presence of ascitic fluid in subject 3 did not interfere with adipose tissue measurements because of their different signal intensities.

Fat volume was measured in each slice by mapping various adipose tissue compartments on the computer screen using a track-ball (Fig. 2). Intraabdominal adipose tissue was distinguished and separated into intraperitoneal and retroperitoneal adipose tissue compartments (Fig. 2). Anatomical points, such as ascending and descending colon, aorta, and inferior vena cava were used as markers for separating the two compartments. A section of abdominal subcutaneous tissue was studied in one body (subject 3) and, to have visible markers on the MRI images in this body, capsules containing vitamin E were placed at the corners of a 10 cm × 10 cm area on the anterior abdominal wall between the xiphoid and the umbilicus before MRI was performed. The markers were placed 5 cm lateral to the midline, and were easily identified on the MRI images.

The number of pixels counted in each compartment was converted into a volume (multiplying the number of pixels by 0.04 $cm^3$). Assuming that adipose tissue is composed of 84.67% fat, 12.67% water, and 2.66% proteins (27), the density of adipose tissue was calculated to be 0.9196 kg/l. Therefore, adipose tissue mass was calculated in kilograms for each 10-mm slice. The masses obtained

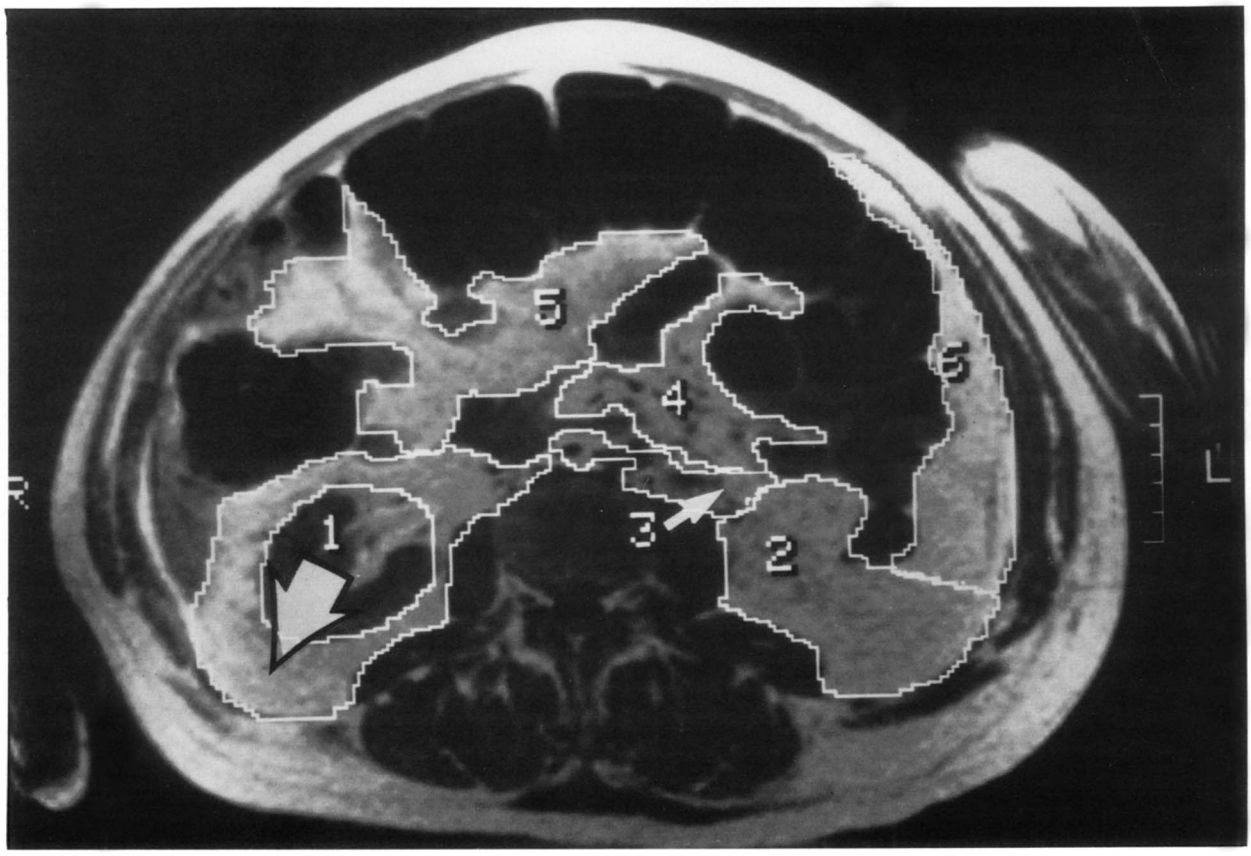



**Fig. 2.** Representative MRI image with outlined intraabdominal adipose tissue compartments. Sections 1, 2, and 3 constitute retroperitoneal adipose tissue. Sections 4, 5, and 6 constitute intraperitoneal adipose tissue.

TABLE 2. Adipose tissue mass measured by MRI and dissection

| | Adipose Tissue Mass (kg) | | | | | |
|---|---|---|---|---|---|---|
| | Subcutaneous | | Intraperitoneal | | Retroperitoneal | |
| | Autopsy | MRI | Autopsy | MRI | Autopsy | MRI |
| Subject 1 | N.A. | N.A. | 1.860 | 1.956 ± 0.076 | 0.750 | 0.848 ± 0.090 |
| Subject 2 | N.A. | N.A. | 2.410 | 2.439 ± 0.070 | 1.200 | 1.374 ± 0.149 |
| Subject 3 | 0.150 | 0.156 ± 0.003 | 1.100 | 1.248 ± 0.155 | 0.530 | 0.523 ± 0.002 |

MRI data are presented as means ± SD from five repeated measurements; N.A., not available.

for each slice were summed to calculate the total adipose tissue mass for each identified compartment (subcutaneous, intraperitoneal, retroperitoneal).

### Dissection

The cadavers studied were dissected within 12 h after the MRI study. The abdomen was opened by a midline incision, and the intestines were removed. The mesentery was separated from the intestinal walls and its weight was determined using a Mettler PC 4400 scale (Mettler Instrument Corporation, Hightstown, NJ).

Likewise, the omentum was also excised and weighed. Perirenal adipose tissue and kidneys were removed together, and the adipose tissue was weighed after it was dissociated from the kidneys. Thereafter, peripancreatic and periaortic adipose tissues were also dissected and weighed. The periaortic, peripancreatic, and perirenal adipose tissues were grouped as retroperitoneal adipose tissue. Mesenteric and omental adipose tissue components were grouped as intra-peritoneal adipose tissue. Skin and subcutaneous adipose tissue were excised from the abdominal wall section delimited by the vitamin E capsules in subject 3. Subcutaneous adipose tissue was then separated from the cutis and weighed.

### Statistical analysis

Data are presented as mean ± SD (standard deviation). The MRI measurements for each compartment were repeated five times by the same investigator (N.A.), who was blinded as to which patient was being measured. The calculations and comparisons were made after collecting all the data. The intra-observer reproducibility of the measurements for the same MRI acquisition was assessed by calculating the coefficient of variation for each adipose tissue compartment measurement. The limits of agreement between the MRI and the dissection data were calculated by evaluating the mean and SD of the differences between the two methods for the same adipose tissue compartment measured (28). The 95% confidence interval for the mean was calculated.

## RESULTS

The data obtained for the adipose tissue mass using the two techniques are reported for each subject in **Table 2.** Overall, MRI measurements slightly overestimated adipose tissue mass, except for the intraperitoneal compartment of subject 2 and the retroperitoneal compartment of subject 3.

An overall comparison of the data obtained with MRI and dissection is given in **Fig. 3.** All of the comparisons, regardless of site, are shown on this graph. If the two methods were to give exactly the same results, all the observation points should have fallen on the identity line. Agreement generally was high although not perfect. Another way to evaluate the accuracy of MRI is

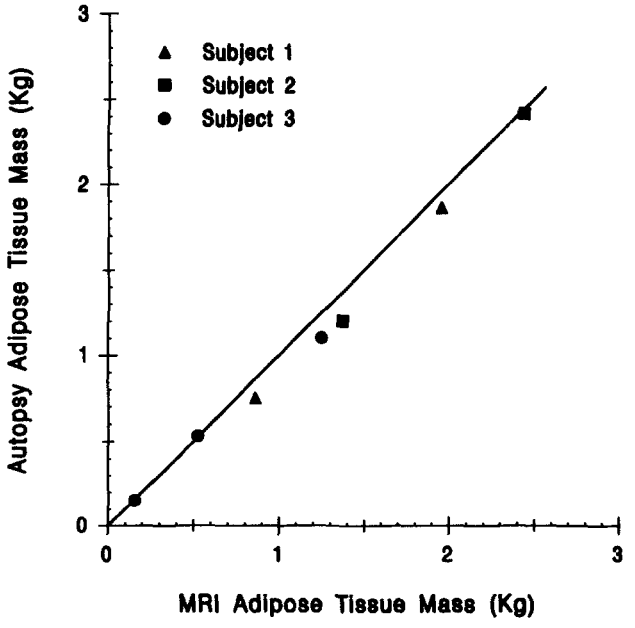



**Fig. 3.** Plot of adipose tissue mass measurements obtained by MRI and direct weighing, with the identity line. The distance of the individual points from the identity line represents the degree of agreement between the two methods.

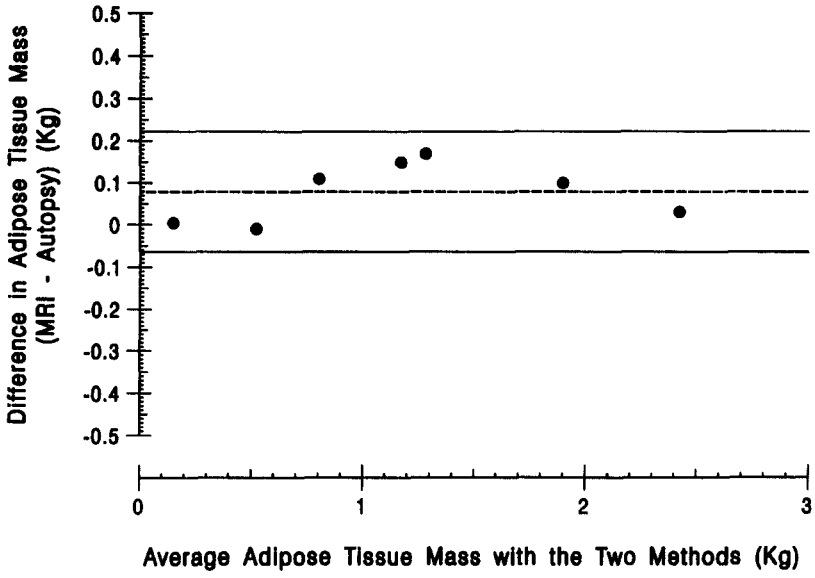



**Fig. 4.** Difference against the mean for adipose tissue mass data. The dashed line shows the mean of the differences between MRI and dissection measurements. The 95% confidence interval for the mean of the differences between the two methods was −0.005 kg and +0.147 kg. The full lines delimitate the limits of agreement between the two methods; 95% of the differences between MRI and dissection lie within this interval.

represented in **Fig. 4.** The difference between MRI and dissection measurements is an estimate of the agreement between the two methods. The average difference between the two methods was found to be small [0.076 ± 0.071 (SD) kg]; MRI appeared to give a slightly higher value than that of dissection. The limits of agreement (mean of the differences ± 2 SD) was −0.066 kg to +0.218 kg; and the 95 percent confidence interval for the mean of the differences was calculated to be −0.005 kg to +0.147 kg.

**Table 3** gives the coefficient of variation on repeated measurements for each MRI-determined compartment of adipose tissue. This coefficient of variation varied from 0.4% to 13.7%, and was highest in the evaluation of retroperitoneal fat for subject 1. When the MRI data on intraperitoneal and retroperitoneal adipose tissue masses were combined together (intraabdominal adipose tissue mass), the coefficients of variation for MRI measurements were below 9%.

## DISCUSSION

The growing evidence that various adipose tissue compartments are metabolically distinct has given a new impetus to research on the metabolic complications of different forms of obesity. Of particular interest is the intraabdominal accumulation of fat that may have unusually high metabolic activity. Abdominal obesity has been claimed to be an important cause of insulin resistance, dyslipidemia, and hypertension (1–6). An excess of abdominal adipose tissue is widely believed to be identified by an increase in waist-to-hip circumference ratio. However, waist-to-hip circumference ratios provide only a rough indication of the amount of adipose tissue in and around the abdomen (29–33); the ratio gives no indication of the absolute amount of adipose tissue within the abdomen.

CT is another method that has been used to estimate abdominal fat. This method has the advantage of visualizing subcutaneous and intraabdominal fat. It has generally been used to provide an estimate of the percentage area of a given "slice" of abdomen occupied by adipose tissue. Previous studies suggest that excess intraabdominal fat, as detected by CT, is accompanied by an increased frequency of metabolic abnormalities (34–36). CT estimates of areas of adipose tissue in abdominal sections have been validated in cadavers (37). However, validation for volume or mass of adipose tissue in cadavers has not been carried out for CT. Therefore, the accuracy of CT in the estimation of adipose tissue "mass" in various compartments is not known.

MRI has several potential advantages over CT for estimating adipose tissue mass. One advantage is the absence of radiation exposure. Another is its ability to determine the volume of a compartment, in contrast to an area

TABLE 3. Intraobserver coefficient of variation for each adipose tissue compartment

| | Compartment | | | |
|---|---|---|---|---|
| | Subcutaneous | Intraperitoneal | Retroperitoneal | Intraabdominal |
| | *Coefficient of Variation (%)* | | | |
| Subject 1 | N.A. | 3.9 | 13.7 | 5.3 |
| Subject 2 | N.A. | 2.9 | 11.1 | 5.2 |
| Subject 3 | 2.2 | 12.0 | 0.4 | 8.7 |

N.A., not available.

of a slice through the compartment, as previously provided by CT. Such a measurement by CT would require a high radiation exposure. A third advantage of MRI is a better definition of adipose tissue than given by CT. The latter benefit is made possible because adipose tissue is easily identified on MRI images because fat has short T1 and long T2 proton relaxation times as compared to other tissues (26). Adipose tissue is distinctly visualized as a bright area that contrasts with surrounding tissues. Although there are a few other substances that may appear bright on T1-weighted images (i.e., flowing blood, recent hemorrhage, lipid content in bowel), interference is rare in the regions of the body where fat is present. The visual definition of the studied anatomical areas furthermore can prevent possible overestimation errors due to the nonadipose tissue, T1-weighed images.

The present study represents an attempt to estimate the volume (and mass) of adipose tissue in humans by MRI and to validate the estimates by direct comparison with dissection. Abdominal adipose tissue was chosen as the target of the study because it has been reported to be unusually metabolically active and because no reliable anthropometric measurements are available to estimate intraabdominal adipose tissue in vivo. The measurements of intraabdominal adipose tissue were extended to distinguish between visceral (intraperitoneal) and retroperitoneal adipose tissue masses. The distinction between these two regions seems relevant, because the anatomical vascular connections of the intraperitoneal space differ from those of the retroperitoneal space. The former drains into the portal vein whereas the latter drains into the inferior vena cava. It has been postulated that the direct exposure of liver cells to high concentrations of free fatty acids and/or other metabolites derived from the intraperitoneal adipose tissue may account for the high frequency of metabolic complications associated with abdominal obesity (38). Intraperitoneal fat may be metabolically different from retroperitoneal fat, and probably should be distinguished from it.

The data of this study reveal that MRI is an accurate technique for determining adipose tissue mass in the abdomen. It can also be used to separately measure intraperitoneal and retroperitoneal adipose tissue masses. The average difference between the MRI estimate and the direct measurement by dissection was less than 80 grams, which means that MRI overestimated intraabdominal fat by less than 5%. This bias was found to have a 95% confidence interval of about 140 grams. Even this limit of estimation error should have little clinical relevance.

The data on the intra-observer reproducibility of MRI measurements indicate that it is also a precise method (Table 3). Even though data on repeated MRI acquisitions are not available in the present study, previous studies in vivo have shown a similar degree of reproducibility for repeated MRI acquisitions (39). Short duration of each acquisition should also minimize the potential effects of respiratory movements and intestinal peristalsis in living human subjects on adipose tissue detection. Therefore, MRI appears to be a potentially valuable method for the in vivo estimation of adipose tissue mass.

Another observation from this investigation was the relatively narrow range of intraperitoneal adipose masses between subjects. The three cadavers studied had a wide range of BMIs (Table 1). But the mass of adipose tissue in the intraperitoneal compartment in the most obese cadaver (subject 2) was only 1.3 kg higher than that of the leanest subject (subject 3) (Table 2). This raises the question of whether such small differences in absolute adipose masses could account for major differences in metabolic complications. The answer to this question, of course, awaits more extensive investigation. The results do, however, point out that if differences in intraperitoneal adipose tissue masses are to be hypothesized to produce significantly different metabolic consequences, precise measurements of the masses in this compartment will be required.

In summary, the present study validates MRI as a precise and accurate technique to study adiposity in humans in vivo. This investigation further shows that MRI is an excellent technique to evaluate different adipose tissue compartments (such as intraperitoneal and retroperitoneal) not accessible by more conventional anthropometric measurements. The use of MRI in the evaluation of adipose tissue distribution should improve our understanding of the impact of regional adiposity on the metabolic complications of obesity.

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