Assessment of abdominal fat content by computed tomography

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ABSTRACT

Computed tomography (CT) produces thin cross-sectional radiographs that may prove very useful in body composition research. CT images of the abdomen allow computerized measurement of total fat area, and also enable the differentiation of subcutaneous fat from intraabdominal fat. The present investigation examines whether a single CT scan of the abdomen provides an accurate indication of overall abdominal adiposity. Graphs of measurements from seven sequential scans of the abdomen in eight patients showed that rankings of total abdominal area, total fat area, subcutaneous and intraabdominal fat area are relatively consistent no matter which abdominal level is chosen. Correlations of 0.89 to 0.99 between single scans and the average values for all scans show that a single CT image contains the same information on adiposity as a series of scans. These results suggest that future CT studies of body composition can limit radiation exposure by using single scans at different anatomical sites. If only a single scan at one site can be obtained, the level of the umbilicus may be the most useful, because it contains the largest percentage of fat in the body, and best allows differentiation of intraabdominal from subcutaneous fat. Am J Clin Nutr 1982;36:172–177.

KEY WORDS

Body composition, computed tomography, obesity, radiology

Introduction

Body fat assessment techniques in vivo measure either total body fat content or subcutaneous fat thickness at particular sites. Densitometry, total body water, and whole body potassium counting have been the most widely used methods of measuring overall obesity, but there is no acknowledged absolute measure of total fat in living subjects. Existing methods are all based on questionable assumptions about constancy of body composition within the fat and lean compartments (1–3). The most widely used site-specific technique uses skinfold calipers to pinch the skin and fat externally. This method is inexpensive, fast, and noninvasive, although its accuracy has been questioned (4, 5). Ultrasound has also been explored for this purpose, but does not substantially improve on skinfold calipers (6, 7). Standard soft tissue radiographs can depict fat thickness, but problems of radiation exposure, subject positioning, and magnification occur (4, 8, 9). Although configurations of physique and fat distribution are of typological interest and may have clinical implications, the site specific measurements are generally used to predict total body fat content (10–12).

Computed tomography (CT) offers the possibility of combining site specific and whole body methods of measuring fatness. CT scans are thin cross-sectional, radiographic images that can be obtained at any

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body level. CT is much more sensitive to slight differences in attenuation than standard radiography and therefore depicts the soft tissues with great clarity (13, 14). As in standard radiography, fat has lower attenuation than other tissues and has a distinct appearance on the CT image (15, 16). Because CT scans are computer reconstructions of thousands of separate determinations of attenuation, the data can be analyzed statistically using CT software. A number of heretofore impossible measurements can be made, including total fat area of a single section, and the combination of areas from successive sections to compute fat volumes. The computer software enables the user to encircle any portion of the anatomy and obtain the area of fat and lean tissue within by specifying the appropriate attenuation ranges. In the abdomen, this feature permits the differentiation of subcutaneous fat area from intraabdominal fat area. Measurements of fat between muscles in the extremities can also be made.

Several studies have documented the value of CT scans in assessing lean tissue (17-19), but none has evaluated its potential for measuring adiposity. This paper investigates the value of single CT scans as representative of the fat distribution in the abdomen as a whole.

Materials and methods

All scans were made using an Ohio Nuclear Delta 2010 CT scanner located in the Department of Radiology, VA Medical Center, Boston. All scans were performed in the supine position with a diameter of 40.3 cm and thickness of 1.0 cm. Images were generated with a 50 MA, 120 KV beam for a duration of 2 s. Scans are displayed in a matrix of 256 × 256 picture elements (pixels). Density scores (CT attenuation numbers) range from −1000 (air) to +1000 (dense bone) with zero representing the density of water. Daily calibration assures variation of less than ±5 units around water density.

Data from eight male inpatients, ranging in age from 25 to 81 yr, comprise this report. Each patient had a CT examination for a variety of suspected medical conditions. Although these patients were not normal volunteers, they were free of gross abdominal disease that might affect the distribution of fat. Degree of adiposity was not a criterion for selection, only the availability of CT scans at the required anatomical levels. From each subject's examination we selected a sequence of seven images obtained at 2-cm intervals. The center image of the sequence was the umbilicus, with three scans above and three scans below this level.

The density of fat is unique, being greater than gas but lower than water or lean tissue. However, our pixel density analyses of fat and lean tissue demonstrated considerable density variability by site and between individuals. This variation results in part because each pixel score is calculated from the attenuation of all x-ray beams passing through that point in the body. This sampling yields random statistical variation. A systematic bias in CT numbers arises from streak artifacts caused when the x-ray beams pass through very high attenuation material (bone, metal) or very low attenuation material (intestinal gas). The effect of streak artifacts is to lower the CT numbers of pixels which are “behind” the bone or gas. We corrected for these artifacts by modifying the range of CT attenuation numbers classified as fat, rather than by using complex correction procedures (20). We found the possible error, introduced by bone artifact in classifying lean tissue as fat, was less than 5% and was relatively constant between individuals.

Our sampling of CT numbers in fat and lean tissue revealed a mean fat CT score of −126.5 and a mean lean score of +23.7. As may be seen in the sample histogram in Figure 1, the fat and lean peaks are separated by a U-shaped intermediate range. This corresponds to pixels which contain both fat and lean tissue and consequently have scores between the two tissue densities (partial volume effect). Our pixel analysis indicated an average CT score of −51.4 for pixels which are half fat and half lean. By rounding this value to an upper cutoff of −50, we balance the error of classifying lean tissue as fat by excluding the same amount of fat tissue misclassified as lean. The lower fat density cutoff was chosen as −250, much below normal fat, but this allowed for the lowered density of fat by bone artifact. These ranges risk some misclassification of air as fat (the left shoulder of the fat peak), and misclassification of bone as lean (the right peak) of the histogram.

![Sample histogram of CT attenuation scores](https://academic.oup.com/ajcn/article-abstract/36/1/172/4693438)

**FIG. 1.** Sample histogram of CT attenuation scores obtained from an umbilicus level image. The left peak represents fat and the smaller right peak represents lean tissue. Zero is the attenuation of water. The lowest point between the two peaks (−50) represents pixels that contain half fat and half lean tissue. The admissible range of CT attenuation scores classified as fat was −50 to −250.
shoulder of the lean peak), both attributable to the partial volume effect. However, these sources of error should be small and rather constant between individuals. We tested several other ranges, and found that shifting the range of CT numbers could change the fat areas by several percent, but the relative rankings of subjects in terms of fatness held constant. Another approach not explored in this study is to limit the criteria for fat and lean to only those CT numbers certain to be the tissue of interest (by taking only a narrow range around the fat and lean peaks). Testing the relative merits of this approach versus the one we used (wide range) needs to be undertaken, although this would require comparison of CT tissue areas using different attenuation ranges with laboratory quantification of fat and muscle from the scanned specimens.

The following computerized area measurements were made from each scan: total tissue area, total fat area, and intraabdominal fat area. The latter was obtained by outlining the transversalis fascia using a cursor. The intraabdominal fat area was subtracted from total fat area to yield subcutaneous fat area. Ratios of total fat area to total tissue area and intraabdominal fat area to total fat area were also calculated. These measurements were made using software available with the Delta 2010 scanner, and can be accomplished with most modern CT equipment. A program to measure areas could be specially written for CT scanners on which such software is not standard.

Results

The CT scans of the abdomen in Figure 2 show some of the variability in fatness in these eight subjects. These include individuals with: typical fat distribution (A), little intraabdominal fat (B), preponderant intraabdominal fat (C), and preponderant subcutaneous fat (D).

Graphs of the data for the seven cross-sections for each subject are shown in Figure 3. Of interest is the extent to which individuals “track” with respect to each other, as shown by whether the lines are relatively parallel and do not cross. Better tracking implies that relative rankings of subjects ob-

![Fig. 2. Umbilicus level CT scans of four patients demonstrating variation in fat distribution. A, normal distribution of intraabdominal fat (IF) and subcutaneous fat (SF); B, patient of muscular habitus with little body fat. Note how bowel (B), opacified with orally administered contrast agent, occupies most of the intraabdominal space. P, psoas muscle; PS, paraspinous muscle; R, rectus abdominis muscle; M, muscles of lateral abdominal wall; C, patient with extensive intraabdominal fat but very little subcutaneous fat. A, aorta; I, inferior vena cava; C, colon; Q, quadratus lumborum muscle. U, umbilicus; D, patient with extensive subcutaneous fat and relatively little intraabdominal fat. Note fatty infiltration of lateral abdominal muscles (arrows).](https://academic.oup.com/ajcn/article-abstract/36/1/172/4693438/174693/4)
FAT MEASUREMENT BY COMPUTED TOMOGRAPHY

FIG. 3. Graphs of CT area data for eight subjects for the sequence of seven abdominal scans. Site distance is in centimeters with 0 representing the umbilicus. Positive numbers are above this level, negative numbers are below. Numbers to the right of each graph are the subject identification numbers. Of interest is the extent to which lines parallel each other and do not cross ("tracking").

Correlation analyses were performed to evaluate the extent to which a single scan is related to the total volume of fat in a 13-cm (7 scan) segment of the abdomen. The average score of each fat parameter was taken across all seven sites and was correlated with the scores from the individual cross-sections. Correlations for all sites are shown in Table I. Despite the extremely small sample size all were highly significant (p < 0.001) indicating that individual CT scans convey the same information as a larger series. Despite some variation in correlation between sites, it is evident that any cross-section is about as well correlated with the mean scores as any other. It should be noted that including the cross-section of interest in the mean of seven sections increases the correlation level, but this does not negate the very strong relationship between single scans and the remainder of the abdomen.

Discussion

It is obvious from simple examination of body CT images that this technique can play a significant role in body composition research. Especially fortunate is the uniquely low attenuation of fat, which makes it readily identifiable. Since the CT scan is a computer reconstruction of a vast number of attenuation readings stored on magnetic tape, computer manipulation of stored data increases the potential applications to body composition studies. Particularly exciting is the ability to specify anatomic regions of interest within which one can quantify fat and muscle areas. Other applications not explored in the present study include evaluation of variation in tissue density throughout the body and between individuals. An additional capability is measurement of the distance between any two points on the image with a user-manipulated cursor, allowing for the accurate measurement of subcutaneous fat thickness.

Due to the cost of CT scanners and their constant use for clinical purposes, it is problematic whether CT will be feasible for large population studies. However, the pictorial clarity and spatial accuracy of CT make it the criterion measure of site-specific adiposity from which to evaluate and calibrate other field methods. Heymsfield et al. (17) have

Intraabdominal fat has its largest area in the upper abdomen, with a gradual decrease in the lower abdomen levels (Fig. 3D). Subcutaneous fat shows considerable variation between subjects but tends to be most extensive below the umbilicus (Fig. 3E). When internal fat is viewed as percentage of total fat (Fig. 3F), the tracking of subjects is less evident. Slightly different rankings of these eight subjects would result depending on the site selected. However, the percentage of internal fat found in the umbilicus cross-section is closest to the mean of this parameter than are any of the other sections examined.

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used CT to determine arm muscle area, and have shown the limitations of estimates based on triceps skinfold and arm circumference. Further studies should compare CT measures of subcutaneous fat with skinfold calipers and ultrasound measurements, and with estimates of total body fat by the various whole body techniques. One source of already existing data is the large number of clinical CT scans stored on magnetic tape in hundreds of hospitals. These could be of great value in demonstrating body composition differences associated with pathological conditions.

For many applications it will be necessary to examine only healthy individuals, such as in studies of aging. If such studies are undertaken, it will be important to limit the number of scans because of cost and radiation exposure. It was with this in mind that we undertook the study reported here. We focused on the abdomen because abdomen circumference and skinfold thickness have proved to be among the best indicators of total fat (21), and the abdomen is the site of maximal fatness. CT is the only technique that allows quantification of intraabdominal fat, which is the largest fat store after the subcutaneous fat. It has been suggested that subcutaneous fat measurements do not accurately predict total fat because the highly variable intraabdominal fat remains unmeasured (21, 22).

An additional reason for this investigation was to determine if CT measurements of tissue areas are reproducible measures of fatness. The most basic question is whether measurements at one level correlate with those of adjacent levels. While this seems obvious for subcutaneous fat, it is less clear intraabdominally where fat is irregularly distributed.

Our results support the value of CT scans for body composition studies and suggest that a single abdominal CT scan can give a good indication of fat content throughout the abdomen. We favor the umbilicus cross-section because of the ease of locating this landmark and because this cross-section has the maximum ratio of fat to total tissue area. The application of these findings to females needs to be examined, although there is little reason to believe that they would differ. There is virtually no ovarian radiation exposure from an umbilicus CT scan, although lower cross-sections increase this risk. In future studies it might be advisable to take single CT scans at several body sites, rather than take adjacent scans of any single region. Further investigation will be needed to determine which sites correlate best with total fat, but our findings and previous studies suggest that if only a single CT scan is used, the umbilicus is the region of choice.

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