Relation between trunk fat volume and reduction of total lung capacity in obese men

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Watson RA, Pride NB, Thomas EL, Ind PW, Bell JD. Relation between trunk fat volume and reduction of total lung capacity in obese men. J Appl Physiol 112: 118–126, 2012. First published September 22, 2011; doi:10.1152/japplphysiol.00217.2011.—Reduction in total lung capacity (TLC) in obese men is associated with restricted expansion of the thoracic cavity at full inflation. We hypothesized that thoracic expansion was reduced by the load imposed by increased total trunk fat volume or its distribution. Using MRI, we measured internal and subcutaneous trunk fat and total abdominal and thoracic volumes at full inflation in 14 obese men [mean age: 52.4 yr, body mass index (BMI): 38.8 (range: 36–44) kg/m²] and 7 control men [mean age: 50.1 yr, BMI: 25.0 (range: 22–27.5) kg/m²]. TLC was measured by multibreath helium dilution and was restricted (<80% of the predicted value) in six obese men (the OR subgroup). All measurements were made with subjects in the supine position. Mean total trunk fat volume was 16.65 (range: 12.6–21.8) liters in obese men and 6.98 (range: 3.0–10.8) liters in control men. Anthropometry and mean total trunk fat volumes were similar in OR men and obese men without restriction (the ON subgroup). Mean total intraabdominal volume was 9.41 liters in OR men and 11.15 liters in ON men. In obese men, reduced thoracic expansion at full inflation and restriction of TLC were not inversely related to a large volume of (1) intrathoracic or abdominal fat, (2) subcutaneous fat volume around the thorax, or (3) total trunk fat volume. In addition, trunk fat volumes in obese men were not inversely related to gas volume or estimated intrathoracic volume at supine functional residual capacity. In conclusion, this study failed to support the hypotheses that restriction of TLC or impaired expansion of the thorax at full inflation in middle-aged obese men was simply a consequence of a large abdominal volume or total trunk fat volume or its distribution.

abdominal volume; intrathoracic volume; magnetic resonance imaging; trunk fat distribution

The cause of the reduction in gas volume at full inflation [total lung capacity (TLC)] found in some obese subjects is unknown. Recently, we compared the total intrathoracic volume at full inflation (TITV; measured by MRI) with TLC in 14 middle-aged obese men, 6 of whom had restriction of TLC (<80% predicted value; the OR subgroup) (30). The objective was to assess whether TLC was reduced by (1) an increase in intrathoracic fat volume or (2) impaired expansion of the thorax. Although both intrathoracic fat (mainly pericardial and mediastinal) and the volume of the heart and major blood vessels were significantly increased in obese men compared with seven control men, these volumes were similar in the OR subgroup compared with obese men without restriction of TLC (the ON subgroup). The major difference between the OR and ON subgroups was that the mean total intrathoracic volume was 105% of the predicted TLC in the former group but 124% of the predicted TLC in the latter group. Therefore, reduced expansion of the thorax at full inflation was the major cause of restriction of TLC in these obese men.

In 1964, Sharp and colleagues (22) showed that the displacement of the relaxed pressure-volume curve of the chest wall to higher pressures found in supine obese subjects could be simulated in normal subjects by external mass loading of the thorax and abdomen. Since this classic study, the dominant physiological hypothesis has been that the reduction in functional residual capacity (FRC) in obesity is a passive effect of increased trunk fat volume. A recent review (20) has suggested that reduction in TLC was probably also due to a mechanical effect of increased adipose tissue. Total trunk fat volume and its distribution vary greatly between obese individuals of similar body weight and body mass index (BMI) (27) and thus might account for the variability of restriction of TLC in subjects with similar BMI (10).

Increased trunk fat volume might reduce TLC by several different effects: (1) increased intra-abdominal fat might over-distend and stiffen the muscular abdominal wall (11), increasing the load on the diaphragm and restricting its caudal movement; (2) total abdominal fat volume (intra-abdominal fat plus the surrounding volume of subcutaneous fat) might have a simple mass effect, restricting caudal movement of the diaphragm; and (3) subcutaneous fat around the thorax might impede full expansion of the thorax. In the present study, we examined whether the volume and distribution of trunk fat and abdominal volume (all measured by MRI) are related to TLC and TITV in the 14 obese middle-aged men studied in our previous report (30).

METHODS

Subjects

All subjects were healthy middle-aged men without significant symptoms, in particular with no history of cardiac or respiratory disease, sleep disturbance, breathlessness, or reduced effort tolerance. In control men, the highest BMI was 27.5 kg/m². Obese subjects were seen on a preliminary occasion to establish that their BMI was between 35 and 45 kg/m² (grade 2 or 3 obesity) and that spirometry showed no obstructive features. TLC was not measured at this stage.

Written informed consent was obtained from all subjects, and the protocol was approved by the Hammersmith Research Ethics Committee.

Methods for anthropometry and lung function have been previously published (30). Height, weight, and hip and waist circumference (WC) as well as four skin-fold thicknesses were measured by standard methods (8, 9).
**Lung Function**

Spirometry was measured in the seated position using a portable Vitalograph flowhead (Vitalograph Ltd. Maids Moreton, Bucks, UK). TLC and subdivisions were measured in duplicate in the supine position using the multibreath helium dilution technique (Morgan Benchmark) (5). While attached to a recording spirometer and remaining in a supine position, subjects were trained to take a repeatable full inspiration followed by breath holding for 17s; this maneuver was repeated several times during the (immediately subsequent) MRI scans.

Standard European reference values (18) were used for spirometry and TLC. Although reference values for TLC were obtained in the upright posture, values of supine TLC in normal and obese subjects are only slightly lower (<200 ml) than upright values (2, 28, 29). Reference values for supine FRC are not available but presumably vary with subject height and so have been expressed as a percentage of the predicted TLC value (%predTLC).

**MRI**

*Acquisition.* Using a Philips Achieva 1.5-T MRI scanner with a Q-Body Coil (Philips Medical System, Best, The Netherlands), a T1-weighted turbo spin echo sequence that covered the entire chest and abdomen was acquired (30). Subjects lay in a supine position with their arms by their side and their hips and knees slightly flexed and were instructed to make a full inflation and then breath hold for 17s while images were acquired in the coronal plane (see Fig. 1 in Ref. 30). Coronal scans fully defined the diaphragm and allowed the separation of abdominal and thoracic volumes.

In one control man and in one obese man additional transverse scans of the abdomen were obtained during breath holding at full inflation while lying supine. These scans were used to clarify the subdivision of abdominal volume into different compartments.

*Analysis.* Segmentation into six tissue types was as previously described (25).

### Table 1. Anthropometry, spirometry, and lung volumes

<table>
<thead>
<tr>
<th></th>
<th>Control Group</th>
<th>Obese Group</th>
<th>P Value</th>
<th>Obese Subgroups</th>
<th></th>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ON subgroup</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>(&gt;80% predTLC)</td>
<td></td>
</tr>
<tr>
<td>Number of subjects</td>
<td>7</td>
<td>14</td>
<td>0.53</td>
<td>8</td>
<td></td>
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<tr>
<td>Age, yr</td>
<td>50.1 (9.3)</td>
<td>52.4 (6.3)</td>
<td>0.07</td>
<td>53.1 (6.3)</td>
<td>51.3 (6.9)</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.82 (0.04)</td>
<td>1.77 (0.1)</td>
<td>&lt;0.0001</td>
<td>122.2 (11.5)</td>
<td>119.3 (11.7)</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>82.4 (8.0)</td>
<td>120.0 (11.2)</td>
<td>&lt;0.0001</td>
<td>38.9 (2.2)</td>
<td>38.7 (2.4)</td>
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<tr>
<td>Body mass index, kg/m²</td>
<td>25.0 (2.2)</td>
<td>38.8 (2.2)</td>
<td>&lt;0.0001</td>
<td>128.3 (9.4)</td>
<td>126.0 (7.6)</td>
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<tr>
<td>Waist circumference, cm</td>
<td>92.2 (4.0)</td>
<td>127.3 (8.4)</td>
<td>&lt;0.0001</td>
<td>1.03 (0.1)</td>
<td>1.00 (0.03)</td>
</tr>
<tr>
<td>Waist/hip ratio</td>
<td>0.93 (0.1)</td>
<td>1.02 (0.1)</td>
<td>0.0002</td>
<td>115.8 (15.1)</td>
<td>124.3 (9.7)</td>
</tr>
<tr>
<td>Sum of skin folds, mm</td>
<td>53.2 (22.0)</td>
<td>119.7 (13.2)</td>
<td>&lt;0.0001</td>
<td>115.8 (15.1)</td>
<td>124.3 (9.7)</td>
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<tr>
<td>Seated</td>
<td></td>
<td></td>
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<tr>
<td>FEV₁ Lmers</td>
<td>4.12 (0.8)</td>
<td>3.45 (0.8)</td>
<td>0.07</td>
<td>3.81 (0.8)</td>
<td>2.97 (0.4)</td>
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<tr>
<td>%predicted</td>
<td>106.0 (14)</td>
<td>95.9 (15)</td>
<td>0.155</td>
<td>105.5 (13)</td>
<td>83.2 (5)</td>
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<tr>
<td>FEV₁/VC ratio</td>
<td>0.76 (0.07)</td>
<td>0.81 (0.06)</td>
<td>0.34</td>
<td>0.80 (0.08)</td>
<td>0.82 (0.05)</td>
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<tr>
<td>Supine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>TLC Lmers</td>
<td>7.15 (0.8)</td>
<td>5.96 (1.3)</td>
<td>0.04</td>
<td>6.83 (0.9)</td>
<td>4.81 (0.6)</td>
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<tr>
<td>%predicted</td>
<td>96.0 (8)</td>
<td>84.2 (15)</td>
<td>0.08</td>
<td>95.4 (10)</td>
<td>69.2 (4)</td>
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<tr>
<td>FRC Lmers</td>
<td>3.32 (0.5)</td>
<td>2.13 (0.7)</td>
<td>0.0013</td>
<td>2.51 (0.8)</td>
<td>1.61 (0.3)</td>
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<tr>
<td>%predictedTLC</td>
<td>44.6 (7)</td>
<td>29.9 (10)</td>
<td>0.0022</td>
<td>34.9 (10)</td>
<td>23.2 (3)</td>
</tr>
</tbody>
</table>

Values are means (SD). ON subgroup, obese men without restriction of total lung capacity [TLC >80% of predicted value]; OR subgroup, obese men with restriction 80% predicted. P values for controls vs. obese men and for ON vs. OR subgroups were determined by unpaired t-tests. FEV₁, forced expiratory volume in 1 s; VC, vital capacity; FRC, functional residual capacity. All data in this table (except for FRC in %predTLC) have been previously published (30).
Calculation of Trunk Volumes

The total volume of the thorax was divided into intrathoracic and extrathoracic volumes.

Intrathoracic cavity volume. Intrathoracic cavity volume was bounded caudally by the diaphragm and cranially at the level of the lung apices and was subdivided into three volumes: 1) total lung volume, which was the volume of intrapulmonary gas, tissue, blood, and fluid and of the major intrathoracic, but extrapulmonary, airways; 2) intrathoracic fat; and 3) the heart and major blood vessels (the aorta, superior vena cava, and major hilar extrapulmonary vessels) as well as other mediastinal structures (e.g., the esophagus).

We refer to the sum of volumes 2 and 3 as the mediastinal volume. All lung gas volumes and all MRI volumes were measured in liters. Empirically, the total intrathoracic volume was also expressed as %predTLC. We do not know of any data relating heart and/or mediastinal volumes to height or to TLC.

Extrathoracic volume. The total volume external to the thoracic cavity was measured; this comprised the volume of the bony-muscular wall of the thorax as well as muscles, bones (scapulae), skin, and subcutaneous tissues external to the thoracic wall. The only part of this extrathoracic volume that was separately measured was subcutaneous fat around the thorax, which extended from the cranial boundary of the thorax to a caudal boundary defined by the costophrenic angles in a midcoronal slice. This boundary was extended transversely so that in ventral coronal slices it was slightly caudal and in dorsal slices slightly cranial to the midcoronal costophrenic angles. In the axillae, only fat directly lining the rib cage was included. The remaining extrathoracic volume, for simplicity, was called the “thoracic wall.”

Total abdominal volumes. Total abdominal volumes were also divided into intra-abdominal and extra-abdominal volumes.

Intra-abdominal volume. This comprised the subdiaphragmatic volume internal to the bony-muscular wall of the abdomen and included all intra- and retroperitoneal organs, blood vessels, and tissues (Fig. 1). MRI scans extended caudally into the pelvis, but included all intra- and retroperitoneal organs, blood vessels, and tissues (Fig. 1). MRI scans extended caudally into the pelvis, but included all intra- and retroperitoneal organs, blood vessels, and tissues (Fig. 1). MRI scans extended cranially at the level of the upper limbs, including and the surrounding volumes of abdominal and thoracic cavities at full inflation as well as the internal fat (shaded ovals) and surrounding subcutaneous fat (hatched regions) in 7 control men and 14 obese men. Volumes of the thoracic and abdominal walls are not shown in these diagrams.

RESULTS

Anthropometry, Spirometry, TLC, and FRC

Anthropometry, spirometry, TLC, and FRC are shown in Table 1. Obese men were, on average, 5 cm shorter than control men. The 14 obese men were divided into 2 subgroups: the OR subgroup (TLC < 80% of the predicted value, n = 6) and the ON subgroup (TLC > 80% of the predicted value, n = 8) It was fortuitous that 6 of the 14 obese men had TLC < 80% of the predicted value. TLC was not found to be a significant discriminator between OR and ON men in mean values of any of the anthropometric features. OR men had smaller supine FRC (%predTLC) compared with ON men (P = 0.018).

Fat and Trunk Volumes

Fat and trunk volumes are shown in Fig. 2 and Table 2. The mean volumes of intra-abdominal and intrathoracic fat and the surrounding volumes of abdominal and thoracic subcutaneous fat were two to three times larger in obese men than in control men (Fig. 2). The largest fat compartment in both obese and control men was subcutaneous fat around the thorax, which in both groups accounted for 43% of the total trunk fat. The intra-abdominal fat volume was seven to eight times the intrathoracic fat volume in both obese and control men. These mean results concealed great between-individual variability within both groups, as shown in subsequent figures.

Thoracic Volumes

Intrathoracic volume. Lung volume was smaller in obese men than in control men, but both compartments of mediastinal volume (the heart and major blood vessels and intrathoracic fat) were significantly larger in obese men than in control men. Lung tissue volume was similar in obese and control men (30).

Mean TITV was only slightly smaller in obese men than in control men. Mean TITV was considerably smaller in OR men...
The mean intra-abdominal volume was 4.23 liters larger in obese men than in control men (P = 0.001), with large variability between individual obese men (Fig. 4).

Most of this variability was due to the internal fat volume, which ranged from 3.0 to 8.0 liters in obese men and from 0.7 to 2.8 liters in control men. Liver volume was also consistently larger in obese men than in control men (P = 0.005; Table 2).

The intra-abdominal volume-to-intrathoracic volume ratio was 1.27 (range: 1.12–1.46) in obese men compared with 0.69 (range: 0.57–0.81) in control men; mean values of this ratio were similar in OR (1.29) and ON (1.25) men because both internal fat volume and total intra-abdominal volume in control and obese men. There was a linear relation between the internal fat volume and total intra-abdominal volume in control and obese men.

The intra-abdominal volume-to-intrathoracic volume ratio was larger in obese men than in control men.

Values of TITV and TLC in individual men. The difference between TITV and TLC varied between 13 and 42%predTLC (Fig. 3). The increased mediastinal volume resulted in a larger mean (SD) value of (TITV-TLC) [32 (7)%predTLC] in obese men than in control men [24 (6)%predTLC, P = 0.02]. Mean (TITV-TLC) was larger in OR men [37 (9)%predTLC] than in ON men [29 (3)%predTLC, P = 0.048], resulting in mean TITV in OR men being 19%predTLC smaller than in ON men compared with a mean difference in TLC of 26%predTLC. The values of TITV in the two men in the ON group in whom TLC was 82%predTLC overlapped with values of TITV in the OR group (Fig. 3).

Extrathoracic and total thoracic volumes. The mean difference in subcutaneous thoracic fat between obese and control men was 4.17 liters or, assuming that 1 liter of fat weighs 0.92 kg, an extra load around the thorax of 3.84 kg (Fig. 2). The thoracic wall volume and total thoracic volumes were also significantly larger in obese men than in control men.
Extra-abdominal and total abdominal volume. In obese men, the relation between the volumes of abdominal subcutaneous fat and intra-abdominal fat was strikingly variable, whereas in control men these two fat volumes were approximately equal (Fig. 5). The mean abdominal wall volume was also larger in obese men than in control men (P = 0.065). The mean total abdominal volume was 6.72 liters larger in obese men than in control men, of which 6.22 liters was accounted for by increases in intra-abdominal and subcutaneous fat and in liver volume in obese men.

Total Trunk Volume

The mean total trunk volume was 11.62 liters larger in obese men than in control men; most of this increase was due to the mean fat volume being 9.67 liters larger in obese men. There were large between-individual differences in total trunk fat in both obese men (range: 12.62–21.85 liters) and control men (range: 2.99–10.81 liters). Internal abdominal fat accounted for 29.6% of the total trunk fat in obese men and 25.9% of the total trunk fat in control men.

The volume of the trunk wall surrounding the intrathoracic and intra-abdominal cavities was also significantly larger in obese than in control men, with most of this difference being due to an increased thoracic wall volume.

Relation of Trunk Fat Volumes to the reduction in TLC and TITV in Obese Men

Mean (SD) values of all fat volumes and abdominal volumes in OR and ON men are shown in Table 2. In these small groups, 95% confidence intervals (CIs) for mean fat volumes were very wide, with none of the differences in fat volumes between OR and ON men approaching statistical significance. As an example, mean CI values of the internal abdominal fat volume were 4.20 (CI: 3.04–5.36) liters in OR men and 5.52 (CI: 4.24–6.80) liters in ON men (P = 0.100). The only mean fat volume that was larger in OR men was subcutaneous abdominal fat (4.14 liters in OR men and 3.59 liters in ON men); this difference did not outweigh the smaller internal fat volume in OR men, so that mean total abdominal fat (sum of internal and subcutaneous fat) was 0.77 liters smaller in OR men.

Figure 6 shows individual values of trunk fat volumes in obese men plotted against TLC and TITV. The OR man who had a large subcutaneous abdominal fat volume but small internal abdominal fat (see Fig. 5) had a TITV 20%predTLC smaller than any other obese man.

The possible relation of a large abdominal fat volume to a reduction in TLC or TITV is shown in Fig. 6, A and B. For internal abdominal fat (Fig. 6A), the trend was in the opposite direction, with the larger fat volumes being in men with larger TLC and TITV. A similar but weaker trend was found for total abdominal fat (Fig. 6B). As expected from the important role of increased fat volumes in increasing intra-abdominal volume (Fig. 4) and total abdominal volume, plots of these abdominal volumes against TLC and TITV (not shown) were very similar to those shown in Fig. 6, A and B, respectively. Plots of subcutaneous thoracic fat volume (Fig. 6C) and total trunk fat volume (Fig. 6D) showed no trend for fat volume to vary over the 40%predTLC range found in TITV and TLC.

Despite considerable interindividual differences in (TITV-TLC) (Fig. 3), plots of trunk fat volumes against TITV showed very similar trends to plots of trunk fat volumes against TLC. In practice, even the largest differences did not invalidate the established use of TLC to detect restriction in obesity.
Relation of Trunk Fat Volumes to Gas and Estimated Intrathoracic Volume at FRC

Fat volumes in individual obese men were also plotted against supine FRC expressed as gas volume or as estimated intrathoracic volume (Fig. 7). To estimate thoracic volume at FRC, the difference between gas and intrathoracic volume was assumed to be unchanged from the value of (TITV-TLC) measured in each individual at TLC.

Plots of total abdominal fat (Fig. 7A) and total trunk fat (Fig. 7B) against volume at supine FRC were similar to plots of fat volumes against TLC and TITV (Fig. 6) in showing no trend for a small FRC volume to be associated with a large fat volume. Plots of internal abdominal fat and thoracic subcutaneous fat against FRC (not shown) also showed no trend for a small FRC to be associated with a large fat volume.

Mean gas volume at FRC in obese men was 15.1%predTLC smaller than in control men \((P = 0.0022; \text{Table } 1)\); in 11 of the 14 obese men, gas volume at supine FRC was smaller than the smallest volume in control men. OR men had a smaller mean gas volume at FRC than ON men \((P = 0.018; \text{Table } 1)\).

The increase in mediastinal volume in obesity has a large role in determining the intrathoracic volume at FRC. Differences in mean intrathoracic volume (SD) between obese \([61.7 (9)\%\text{predTLC}]\) and control men \([68.3 (8)\%\text{predTLC}]\) were smaller than gas volume differences (Fig. 7C) and were not significant \((P = 0.132)\). Mean intrathoracic volumes at FRC in OR men \([59.2 (10)\%\text{predTLC}]\) and ON men \([63.5 (10)\%\text{predTLC}]\) also were not significantly different \((P = 0.428)\). There was a considerable overlap of values of intrathoracic volume at FRC between obese and control men.

Relation of WC to Abdominal Volumes

WC was strongly related to total abdominal volume \((r^2 = 0.76)\) and total abdominal fat (sum of abdominal internal and subcutaneous fat, \(r^2 = 0.80)\) in the total group of control and obese men. The relation of WC to intra-abdominal volume \((r^2 = 0.72)\) and internal abdominal fat \((r^2 = 0.73)\) was weaker.

Distribution of Subcutaneous Fat

The circumferential distribution of subcutaneous fat around the trunk could not be determined from our coronal scans. Therefore, we reviewed archived transverse midabdominal and midthoracic MRI scans in 20 middle-aged men \((8 \text{ normal weight or mildly overweight men and } 12 \text{ obese men})\) who were prone and breathing tidally. The distribution of subcutaneous fat varied between individuals but was almost always more ventral than dorsal at both levels, sometimes strikingly so; hence, the example shown in Fig. 1 in an obese man is atypical. The thickness of abdominal subcutaneous fat was consistently either greater than or similar to that of thoracic subcutaneous fat, suggesting that the larger volume of thoracic subcutaneous fat arose because the thorax had a greater craniocaudal length than the truncated abdomen.

DISCUSSION

We examined whether lung restriction, previously found in 6 of 14 obese men, was associated with large increases in total trunk fat volume or abdominal volume. Restriction was assessed by measuring both total intrathoracic volume and gas volume \((\text{TLC})\) at full inflation. Although there were large between-individual differences in total trunk and abdominal volume in obese men, restriction of gas volume and thoracic expansion at full inflation were not inversely related to a large trunk fat or abdominal volume.

Analysis of MRI Scans

Most previous estimates of fat volume using MRI scans have been based on transverse scans with the subject in a prone position and continuing to breathe tidally. Usually there have been gaps between transverse slices and abdominal and thoracic volumes have not been measured. In contrast, we obtained coronal scans during breath holding to define the diaphragm. It was impractical to reconstruct the circumferential distribution of subcutaneous fat from these scans. We measured the major sites of internal and subcutaneous fat loading inspiration but did not quantify the scattered small collections of fat in the axillae or associated with muscles of the trunk wall.

Using opticoelectrical plethysmography, Sanna and colleagues \((21)\) reported that upright total trunk volume averaged \(25–26 \text{ liters at FRC in four control men, which compares well with the mean trunk volume in our control men of } 30.4 \text{ liters at TLC when allowance is made for an erect inspiratory capacity of } \sim 3.0–3.5 \text{ liters. We are unaware of previous measurements of total abdominal volumes. Internal fat in the abdominal cavity and omentum was distinguished from fatty material within the bowel by an experienced operator. Reassuringly, the}}
volume of intra-abdominal other organs, which included a large contribution from the bowel as well as from solid organs, was similar in obese and control subjects. A previous study (26) of obese subjects in this department has shown that increased liver volume is associated with the accumulation of lipids within hepatic cells.

Choice of Subjects

Subject heterogeneity was reduced by studying only middle-aged white men and restricting the 14 obese men to BMIs between 35 and 45 kg/m². Men were studied because internal abdominal fat is a greater percentage of total body fat in obese men than in obese women (12, 19), studies have shown (see Ref. 30) that the loss of forced vital capacity (FVC) with gain in weight is greater in men than in women. Although a reduction in TLC is a consistent feature of obesity hypoventilation syndrome (17), the current consensus is that in most obese subjects the decrease in FVC or TLC is small or absent (10).

Waist Circumference

In recent years, WC has been increasingly recognized as the best simple measurement of many markers of male obesity. In a recent detailed analysis of a separate group of 70 obese men studied in our department, the strongest correlation of WC, as in our small sample, was with the sum of internal and subcutaneous abdominal fat (total abdominal fat, $r^2 = 0.845$) rather than with intra-abdominal fat ($r^2 = 0.66$) alone.

Four recent cross-sectional population studies (6, 7, 13, 15) have shown that increased WC is associated with smaller FVC.
Relation of Trunk Fat Volume and Abdominal Volume to Restriction of TLC and TITV

Our experiments failed to show any trend for the largest trunk fat volumes to be found in men with small TITV or TLC (Fig. 6). Experimentally in dogs, an acute increase in intra-abdominal volume produced by intra-abdominal fluid infusion has been shown to reduce the distensibility of the abdominal muscular wall and increase intra-abdominal pressure (11). But this acute experiment is of limited relevance to human obesity, in which the increase in intra-abdominal volume develops over many years; the muscular abdominal wall covers a larger total area and becomes thinner (see Fig. 1, right). Rather than an inverse relation between the total volume of intra-abdominal and subcutaneous fat and reduction in TITV and TLC, we found that mean volumes of abdominal fat were slightly smaller in OR men than in ON men (Fig. 6B). Not all subcutaneous abdominal fat loads inspiration, but precise analysis requires knowledge of its distribution and posture of the subject (3).

Another possibility is that the encircling subcutaneous thoracic fat restrains full expansion of the thoracic cage. Neither thoracic subcutaneous fat volume alone (Fig. 6C) or in combination with total abdominal fat volume (Fig. 6D) showed any trend for the largest fat volumes to be in men with small TITV or TLC. Although the number of obese men was small, the results were so negative that we doubt whether they would be reversed by extending the present study. We believe that invasive studies measuring transdiaphragmatic and transpulmonary pressures at TLC are likely to be more productive. Gastric pressure is increased considerably during tidal breathing in obese subjects (4, 23, 24), but we are not aware of studies of inspiratory muscle strength at full inflation.

Relation of Trunk Fat Volumes to Gas and Estimated Intrathoracic Volume at FRC

In our study, gas volume at supine FRC was considerably smaller in obese men than in control men (Table 1 and Fig. 7), but within the obese group there was no trend for men with the largest trunk fat volume to have the smallest FRC; if anything, the reverse trend was observed. However, in severe obesity, we (29, 31) and others (2) have shown that supine FRC hardly falls below seated values and is probably determined actively by the initiation of inspiration at volumes above the relaxation volume (Vr) (16, 31). Recently, Behazin et al. (4) found evidence of positive pleural pressures at supine Vr in many anesthetized obese subjects, but, surprisingly, these pressures did not correlate with BMI or other surrogate markers of obesity.

An earlier MRI study by Babb et al. (1) examined the relation between mean values of erect FRC/TLC and trunk and peripheral fat volumes in groups of lean and obese men and women. Although many estimates of regional fat mass were inversely related to FRC/TLC, the authors were unable to relate a reduction in FRC/TLC to any specific regional distribution of trunk fat.

Because of our negative results, we have reexamined the studies of Sharp and colleagues (22), who aimed to simulate the small FRC and Vr associated with obesity by mass loading the chest wall of supine relaxed normal weight men. The most consistent results, with a fall of ~0.6 liters in Vr, were produced by a mass load of 27.2 kg on the lower rib cage. This load is very large compared with the mean increases in total subcutaneous fat around the rib cage in obese men of 3.84 kg in our study and 3.45 kg in Babb et al.’s study (1).
Because of the increase in mediastinal volume in obese men, their estimated intrathoracic volume at FRC was, on average, only 6.6%predTLC smaller than in normal weight men compared with a 14.7%predTLC difference in gas volume at FRC (Fig. 7C). Hence, the rib cage-diaphragm volume at FRC in obese men is larger than suggested by their small gas volume. However, the intrathoracic volume at FRC was estimated from the value of (TITV-TLC) in each individual, so simultaneous direct measurements of intrathoracic and gas volumes at FRC are required.

In summary, we measured compartments of trunk fat volume in grades 2–3 obesity and their contribution to abdominal volumes. There were large between-individual differences in trunk fat volumes in men of similar age and BMI. When we compared individual values of TLC and FRC with trunk fat volumes in obese men, we did not find an inverse relation between large fat volume and restriction of TLC or reduction of FRC.

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DISCLOSURES
No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

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