What is the best reference site for a single MRI slice to assess whole-body skeletal muscle and adipose tissue volumes in healthy adults?^1

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ABSTRACT

Background: Whole-body magnetic resonance imaging (MRI) is the gold standard for the assessment of skeletal muscle (SM) and adipose tissue volumes. It is unclear whether single-slice estimates can replace whole-body data.

Objective: We evaluated the accuracy of the best single lumbar and midthigh MRI slice to assess whole-body SM, visceral adipose tissue (VAT), and subcutaneous adipose tissue (SAT).

Design: Whole-body MRI was performed in 142 healthy adults aged 19–65 y [mean ± SD age: 37.0 ± 11.8 y; BMI (in kg/m^2): 25.3 ± 5.9] at lumbar vertebrae L1–L5 plus intervertebral discs and the thigh (midthigh, 10 cm distally from the midthigh, and 10 cm proximally from the midthigh). The value of single-slice areas was also tested in a longitudinal study on 48 healthy volunteers during weight loss (8.2 kg).

Results: Cross-sectionally, all SM and adipose tissue single-slice areas correlated with total tissue volumes (P < 0.01). Because of the close associations between L3 areas and corresponding tissue volumes (r = 0.832–0.986, P < 0.01), this location was identified as the reference to estimate SM and adipose tissue in both sexes. SM, SAT, and VAT areas at L3 explained most of the variance of total tissue volumes (69–97%, with SEs of estimation of 1.96 and 2.03 L for SM, 0.23 and 0.61 L for VAT, and 4.44 and 2.47 L for SAT for men and women, respectively. There was no major effect on the correlation explained variance compared with that for optimal slices. For SM, the optimal slice area was shown at midthigh. With weight-loss changes in total SM, VAT, and SAT, volumes were significantly different from those at baseline (SM changes: -2.8 ± 2.9 L; VAT changes: -0.7 ± 1.0 L; SAT changes: -5.1 ± 6.0 L). The area at L3 reflected changes in total VAT and SAT. To assess changes in total SM volumes, areas at midthigh showed the best evidence.

Conclusion: In both sexes, a single MRI scan at the level of L3 is the best compromise site to assess total tissue volumes of SM, VAT, and SAT. By contrast, L3 does not predict changes in tissue components. This trial was registered at clinicaltrials.gov as NCT01737034.

INTRODUCTION

The assessment of skeletal muscle (SM)^5 and adipose tissue (AT) is essential in obesity, aging, and wasting diseases (1, 2). The imaging techniques MRI and computed tomography are gold-standard methods to assess whole-body and regional SM, subcutaneous adipose tissue (SAT), and visceral adipose tissue (VAT). However, the application of MRI is restricted because of a limited availability of devices and high costs. In addition, the manual assessment of whole-body organ and tissue volumes is time consuming. Alternatively, a number of authors replaced whole-body MRI by selected scans to assess SM or AT (3–9), which resulted in different slice locations for each tissue. To our knowledge, no study has investigated one common measurement site to assess SM and AT from a single MRI slice, which would be an enormous progress for the assessment of, for example, sarcopenic obesity.

For individual slices obtained at the lumbar spine, several authors showed strong correlations with total-body VAT, SAT, and AT volumes (3–5, 9–15). With the comparison of different slices, AT areas 5–10 cm above L4–L5 showed the strongest correlations with total VAT volume, whereas for SAT, the measurement site had no considerable effect on the correlation strength.

For SM, there are only a few whole-body MRI databases worldwide (16–18). The use of single slices to estimate whole-body SM has been investigated rarely (3, 19, 20). The area ~5 cm above L4–L5 at the lumbar spine was established as a predictor of total-body SM volume (3). More than 50% of SM is shown in the lower extremities, predominating at the thigh (21).

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^2 Abbreviations used: AT, adipose tissue; MT−10, 10 cm proximally from the midthigh; MT+10, 10 cm distally from the midthigh; SAT, subcutaneous adipose tissue; SEE, SE of estimation; SM, skeletal muscle; VAT, visceral adipose tissue.

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Hence, in addition to lumbar areas, muscle-thigh areas also reflect whole-body muscle mass. Accordingly, a single cross-sectional slice at midthigh was correlated with specific muscle volumes (6, 22–26). However, to assess SM as well as AT, there has been no investigation, to our knowledge, that compared the accuracy of a single slice at the thigh with a single lumbar-slice area.

Some authors assessed the accuracy of single-slice estimates at the abdomen to predict changes of whole-body volumes of AT (14, 15, 27, 28). When compared with cross-sectional data, relations between changes in whole-body AT volume and changes in single areas with weight loss were weaker. Slices at 5–10 cm above L4–L5 were the best estimates of changes in VAT (14, 27, 28). However, different slice locations did not have a major impact on estimates of changes in whole-body SAT (14). Thus far, the assessment of changes in total-body SM, VAT, and SAT volumes by a reference slice has not been investigated.

Accordingly, the aim of the current study was to simplify and standardize the MRI assessment of SM and AT by identifying a common reference slice area for estimates of SM, SAT, and VAT as a replacement of their respective total tissue volumes. Therefore, we systematically investigated single-slice areas at the 5 lumbar vertebrae as well as intervertebral discs to find one common slice for women and men that optimally estimates SM, SAT, and VAT. Three slices at the thigh were included in the analysis to evaluate the prediction of total-body SM and SAT volumes. We investigated the extent of compromise between areas at the thigh and reference areas at the lumbar region. Moreover, we tested the accuracy of single-slice areas to assess changes in total tissue volumes with weight loss.

METHODS

Subjects

This investigation was a secondary analysis of data ascertained between 2005 and 2012 at the Institute of Human Nutrition and Food Science at University of Kiel (Christian-Albrechts-University, Kiel, Germany) (29–31). In the cross-sectional study, MRI data of 142 healthy Caucasians (75 women and 67 men) aged 19–65 y with BMI (in kg/m²) from 20.0 to 47.7 were analyzed. In addition, whole-body MRI data of 48 healthy volunteers, including 24 women (age: 33.1 ± 6.2 y; BMI at baseline: 36.0 ± 5.6; weight loss: 9.0 ± 5.4 kg) and 24 men (age: 28.0 ± 7.7 y; BMI at baseline: 27.2 ± 5.0; weight loss: 7.3 ± 5.0 kg) were selected for longitudinal analyses (for details of the study protocol see references 30 and 31). Sixteen normal-weight men underwent a 3-wk controlled underfeeding at ~50% of their energy needs (30); overweight subjects consumed a nutritionally balanced low-caloric diet of 800–1000 kcal/d for 12.7 ± 2.2 wk (31). All subjects were recruited from the local community and by using a local advertisement as well as notice-board postings. Exclusion criteria were smoking, metallic implants, pregnancy, acute or chronic diseases, and intake of medication that influences body composition. Each participant was informed about the objectives and methods of the study and asked to sign an informed consent. The entire protocols were approved by the ethical committee of the Christian-Albrechts-University. Measurements of body composition took place at the Institute of Human Nutrition and Food Science (anthropometric measures) and the Clinic for Diagnostic Radiology, Universitätsklinikum Schleswig-Holstein (MRI).

Anthropometric measurements

Body weight was measured to the nearest 0.01 kg with an electronic scale coupled to the BOD POD device (TANITA). To assess the height of participants a seca stadiometer (Vogel & Halke) with an accuracy of 0.5 cm was used.

Magnetic resonance imaging

The body composition of all subjects was measured by using whole-body MRI. Protocols were described in more detail elsewhere (31, 32). Organs and tissues were obtained by using a 1.5-T Magnetom Avanto Vision Scanner (Siemens Medical Systems) with a T1-weighted-gradient echo sequence (repetition time: 157 ms; echo time: 4 ms). Transversal scans were obtained from the wrist to ankle with a slice thickness of 8 mm and a 2-mm interslice gap. Participants were analyzed in a supine position with their arms extended above their heads. During the measurement of abdominal and thoracic regions, subjects asked to hold their breath. All volumes of SM, SAT, and VAT were assessed manually by the use of segmentation software (Slicer4.3, Tomovision). SM and SAT were analyzed from the wrist to ankle, whereby arms were defined from the wrist to humerus heads, and legs were defined from femoral heads to the ankle. The trunk was assessed between the humerus and femoral heads. VAT was segmented from the top of the liver to femoral heads. Single cross-sectional areas were ascertained by using specific landmarks. The sacrum was chosen as a standard landmark in the region of the lumbar spine to detect all 5 vertebrae and intervertebral discs. The investigation of the thigh included 3 slices. First, the midthigh was calculated from the middle distance between the distal end of the femoral neck and the first slice showing the intercondylar fossa. In addition, slices 10 cm distally from the midthigh (MT+10) and 10 cm proximally from the midthigh (MT−10) were taken.

Statistical analysis

Descriptive statistics were calculated for the study population. First, the Kolmogorov-Smirnov-method was applied to test for normal distribution. Almost all data were normally distributed and are presented as means ± SDs. Otherwise data are shown as medians (IQRs). For additional analysis, logarithmic values of these data were used. To detect differences in sex, an unpaired t test was applied. Pearson correlation coefficients were used to evaluate bivariate linear relations in all single-slice areas and their respective whole-body volumes. The slice area that showed the closest associations to all whole-body volumes of SM, SAT, and VAT in women and men was determined as the best slice. Differences in their correlation coefficients between all slice areas and reference slice areas were tested by using the method of Steiger (33). Simple linear regressions were applied to evaluate prediction equations with coefficients of determination and SEs of estimation (SEE) for whole-body volumes of SM, SAT, and VAT. Bland-Altman plots were applied to compare SM, VAT, and SAT percentages of whole-body volume and SM, VAT, and SAT percentages of total area of the reference slice. To quantify changes in explained variances, determination coefficients of reference and optimally correlated slice areas were compared. All single-slice areas were ascertained in the subpopulation to obtain changes in component volumes with weight.
loss. Significant intra-individual changes of SM, SAT, and VAT volumes during caloric restriction were tested by using a paired t test. For associations between changes of whole-body volumes and changes of slice areas, Pearson correlations were applied. Differences in intra-individual and sex correlation coefficients were examined by using the methods of Steiger and Fisher’s Z transformation, respectively (33, 34). All statistical analyses were carried out with SPSS version 17.0 software (SPSS Institute). Two-sided (P < 0.05) tests of significance were used.

RESULTS

Subject characteristics

Subjects’ characteristics are summarized in Table 1. Men and women differed significantly in height and weight as well as in whole-body volumes of SM, SAT, and VAT. Men were taller, were heavier, and had higher SM and VAT, whereas SAT was greater in women.

Single-slice areas and total tissue MRI volumes

Mean results for areas of SM, VAT, and SAT at different locations are presented in Figure 1. At the lumbar region, the SM area increased from L1 to L3/L3–L4 with a subsequent decrease. In both sexes, SAT (in men and women) and VAT (in women only) increased from L1 to L5. In men, VAT decreased from L1 to L5. At midthigh, SM and SAT decreased from the upper to the lower reference point in both sexes.

Correlation coefficients between single-slice areas and total tissue volumes ranged between 0.466 and 0.925 in men (Table 2). As for AT, SAT and VAT showed strong and similar correlations between all single-slice areas and total tissue volumes (r = 0.883–0.987, P < 0.01). When compared with AT, there was a greater variance in correlation coefficients of SM (r = 0.466–0.925, P < 0.01). In all cases, slice areas at L3 showed a strong association with total tissue volumes independent of sex. Thus, this location was identified as the best slice for additional analyses. As regards SM, both sexes showed the strongest correlation between individual slice areas and total volumes at the thigh (women: MT+10; men: MT−10). In women, but not in men, the correlation coefficient at MT was significantly higher compared to the correlation coefficient at L3. Between SAT volumes and SAT areas, highest correlation coefficients were observed at L4–L5 (men) and L5 (women), with a significant difference from the correlation coefficient at L3, in both sexes. Best estimates of whole-body VAT volumes were at L3 (in women) and L1–L2/L2 (in men). In men, there were significant differences between reference and optimal slice areas (Table 2).

Figure 2 shows the areas of SM, SAT, and VAT at L3 plotted against their respective total tissue volumes. Prediction equations for total volumes (V) of SM, VAT, and SAT from the slice area at L3 (A) were as follows.

For women:

\[ V_{SM}(L) = 0.141 \times A_{L3} \text{(cm}^2\text{)} + 3.790 \]

\[ (R^2 = 0.692, \text{SEE} = 1.96L) \]  

For men:

\[ V_{SM}(L) = 0.136 \times A_{L3} \text{(cm}^2\text{)} + 5.944 \]

\[ (R^2 = 0.741, \text{SEE} = 2.03L) \]

For women:

\[ V_{VAT}(L) = 0.026 \times A_{L3} \text{(cm}^2\text{)} + 0.121 \]

\[ (R^2 = 0.971, \text{SEE} = 0.23L) \]

For men:

\[ V_{VAT}(L) = 0.025 \times A_{L3} \text{(cm}^2\text{)} + 0.164 \]

\[ (R^2 = 0.909, \text{SEE} = 0.61L) \]

For women:

\[ V_{SAT}(L) = 0.087 \times A_{L3} \text{(cm}^2\text{)} + 5.920 \]

\[ (R^2 = 0.920, \text{SEE} = 4.44L) \]

For men:

\[ V_{SAT}(L) = 0.078 \times A_{L3} \text{(cm}^2\text{)} + 4.487 \]

\[ (R^2 = 0.904, \text{SEE} = 2.47L) \]

TABLE 1

Characteristics of study subjects

<table>
<thead>
<tr>
<th></th>
<th>Women (n = 75)</th>
<th>Men (n = 67)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>38.0 ± 12.1²</td>
<td>38.3 ± 11.5</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.69 ± 0.07³</td>
<td>1.81 ± 0.05</td>
</tr>
<tr>
<td>Body weight, kg</td>
<td>77.4 ± 22.0³</td>
<td>88.6 ± 14.8</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>24.4 (22.1–31.1)⁴</td>
<td>26.3 (23.2–30.0)⁴</td>
</tr>
<tr>
<td>Normal weight (18.5–24.9), %</td>
<td>53.3</td>
<td>38.8</td>
</tr>
<tr>
<td>Overweight (25.0–29.9), %</td>
<td>18.7</td>
<td>35.8</td>
</tr>
<tr>
<td>Obese (≥30.0), %</td>
<td>28.0</td>
<td>25.4</td>
</tr>
<tr>
<td>Total tissue MRI volumes, L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMtotal</td>
<td>21.2 ± 3.5³</td>
<td>31.3 ± 4.0</td>
</tr>
<tr>
<td>SMtrunk</td>
<td>7.1 ± 1.1³</td>
<td>10.9 ± 1.5</td>
</tr>
<tr>
<td>SMlegs</td>
<td>11.1 ± 1.9³</td>
<td>15.5 ± 1.9</td>
</tr>
<tr>
<td>SMarms</td>
<td>2.8 (2.5–3.1)³</td>
<td>4.8 (4.4–5.5)³</td>
</tr>
<tr>
<td>SATtotal</td>
<td>21.4 (17.4–34.7)³</td>
<td>17.3 (12.6–22.3)³</td>
</tr>
<tr>
<td>SATtrunk</td>
<td>8.8 (6.2–15.3)³</td>
<td>7.2 (5.1–10.2)³</td>
</tr>
<tr>
<td>SATTlegs</td>
<td>10.3 (8.0–15.4)⁴</td>
<td>7.7 (6.0–9.4)⁴</td>
</tr>
<tr>
<td>SATlegs</td>
<td>2.5 (1.9–4.0)³</td>
<td>2.3 (1.7–2.9)³</td>
</tr>
<tr>
<td>VATtotal</td>
<td>0.9 (0.4–2.2)³</td>
<td>2.3 (1.1–3.8)³</td>
</tr>
</tbody>
</table>

¹SAT, subcutaneous adipose tissue; SM, skeletal muscle; VAT, visceral adipose tissue.
²Mean ± SD (all such values).
³Significantly different from men, P < 0.001 (unpaired t test).
⁴Median; IQR in parentheses (all such values); not normally distributed data.

Reference slice areas at L3 compared with best-correlated slice areas

The variance of total-body SM, VAT, and SAT could be mostly explained by the best-correlated areas. Coefficients of
determination for the prediction of SM, SAT, and VAT volumes from L3 areas were high as well ($R^2 = 0.692–0.971$). For AT, there were only slight differences in $R^2$ of areas at L3 between sexes. In both men and women, with the use of the reference area for SAT and VAT, $R^2$ decreased by 3.8–6.6%, and SEE increased by 0.29–1.22 L only, compared with the explained variance of best-correlated slice areas. In women, the reference L3 showed the best correlation between the VAT area and total VAT volume.

Determination coefficients of SM areas at best-correlated slices as well as at L3 were lower than those of AT ($R^2$ of SM areas: 0.692–0.855). When compared with men, the explained variance of total-body SM volume in women by using the best correlated SM area was 7% higher with a lower SEE (women: $1.34$ L; men: $1.87$ L). In men, the explained variance of SM volume at the reference L3 was 74.1%, and thus 4.9% higher compared with women (SEE: women = $1.96$ L; men = $2.03$ L). Bland-Altman plots with percentages of SM, VAT, and SAT of total-body volumes and percentages of SM, VAT, and SAT of total slice areas at L3 showed the following agreement.

$SM$

For women:

$$y = -0.145x + 9.648 \left( R^2 = 0.071, \text{SEE} = 2.74\% \right) \quad (7)$$

For men:

$$y = -0.389x + 20.020 \left( R^2 = 0.455, \text{SEE} = 2.40\% \right) \quad (8)$$

$VAT$

For women:

$$y = -0.425x + 0.883 \left( R^2 = 0.736, \text{SEE} = 1.11\% \right) \quad (9)$$

| TABLE 2 |
| Pearson correlations between total tissue volumes of SM, SAT, VAT, and single-slice areas$^1$

<table>
<thead>
<tr>
<th>Correlation coefficient ($r$)</th>
<th>L1</th>
<th>L1–L2</th>
<th>L2</th>
<th>L2–L3</th>
<th>L3</th>
<th>L3–L4</th>
<th>L4</th>
<th>L4–L5</th>
<th>L5</th>
<th>MT–10</th>
<th>MT</th>
<th>MT+10</th>
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<tbody>
<tr>
<td><strong>Women ($n = 75$)</strong></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>SM</td>
<td>0.746$^2$</td>
<td>0.777$^2$</td>
<td>0.816</td>
<td>0.466$^{2,3}$</td>
<td>0.832</td>
<td>0.831</td>
<td>0.756$^2$</td>
<td>0.593$^{2,3}$</td>
<td>0.641$^2$</td>
<td>0.874</td>
<td>0.889$^2$</td>
<td>0.925$^{2,4}$</td>
</tr>
<tr>
<td>SAT</td>
<td>0.944$^2$</td>
<td>0.948$^2$</td>
<td>0.949$^2$</td>
<td>0.901$^{2,3}$</td>
<td>0.959</td>
<td>0.962$^3$</td>
<td>0.968$^3$</td>
<td>0.973$^2$</td>
<td>0.979$^{2,4}$</td>
<td>0.947</td>
<td>0.939$^{2,3}$</td>
<td>0.918$^2$</td>
</tr>
<tr>
<td>VAT</td>
<td>0.971$^4$</td>
<td>0.980$^2$</td>
<td>0.972$^{2,3}$</td>
<td>0.984</td>
<td>0.986$^{3,4}$</td>
<td>0.974$^{3,5}$</td>
<td>0.974$^{2,3}$</td>
<td>0.961$^{2,3}$</td>
<td>0.944$^{2,3}$</td>
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<tr>
<td><strong>Men ($n = 67$)</strong></td>
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<tr>
<td>SM</td>
<td>0.685$^2$</td>
<td>0.769$^2$</td>
<td>0.807$^2$</td>
<td>0.842</td>
<td>0.861</td>
<td>0.871</td>
<td>0.796$^2$</td>
<td>0.776$^2$</td>
<td>0.751$^2$</td>
<td>0.884</td>
<td>0.869</td>
<td>0.859</td>
</tr>
<tr>
<td>SAT</td>
<td>0.946$^2$</td>
<td>0.943$^2$</td>
<td>0.942$^2$</td>
<td>0.945$^2$</td>
<td>0.951</td>
<td>0.963$^2$</td>
<td>0.966$^2$</td>
<td>0.973$^{2,4}$</td>
<td>0.970$^2$</td>
<td>0.926</td>
<td>0.868$^2$</td>
<td>0.868$^2$</td>
</tr>
<tr>
<td>VAT</td>
<td>0.978$^2$</td>
<td>0.987$^{2,4}$</td>
<td>0.987$^{2,4}$</td>
<td>0.975$^2$</td>
<td>0.954</td>
<td>0.906$^2$</td>
<td>0.894$^2$</td>
<td>0.886$^2$</td>
<td>0.883$^2$</td>
<td>—</td>
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</tbody>
</table>

$^1$All correlation coefficients were significant at $P < 0.01$. L, lumbar vertebra; MT, midthigh; MT–10, 10 cm proximally from the midthigh; MT+10, 10 cm distally from the midthigh; SAT, subcutaneous adipose tissue; SM, skeletal muscle; VAT, visceral adipose tissue.

$^2$Significantly different from correlation coefficient at L3 (within tissue and sex), $P < 0.05$ [method of Steiger (33)].

$^3$Significantly different from correlation coefficient in men, $P < 0.05$ [Fisher’s Z transformation method (34)].

$^4$Strongest correlation.
For men:
\[ y = -0.436x + 0.515 \left( R^2 = 0.696, \text{SEE} = 1.91\% \right) \quad (10) \]

**SAT**

For women:
\[ y = -0.425x + 10.490 \left( R^2 = 0.486, \text{SEE} = 4.49\% \right) \quad (11) \]

For men:
\[ y = -0.459x + 5.365 \left( R^2 = 0.564, \text{SEE} = 2.74\% \right) \quad (12) \]

whereby \( y \) equals the difference between the percentage of tissue volume (total-body volume) and the percentage of tissue area (area at L3), and \( x \) equals the mean of the percentage of tissue (total-body volume) and the percentage of tissue (area at L3).

**Estimating changes in SM, SAT, and VAT with weight loss by single-slice areas**

Weight loss of 9.0 ± 5.4 and 7.3 ± 5.0 kg in women and men, respectively, was characterized by decreases in whole-body SM, SAT, and VAT volumes (Table 3). Changes in individual slice areas differed between locations as well as between SM and AT (Figure 3). Similar differences showed associations between changes in total-body volumes and single-slice areas (Table 4). In both men and women, there were no significant correlations between changes of total SM volume and changes of SM at the L3 area. Significant but weak correlations between whole-body volumes and single-slice areas were only seen at L3–L4, L4–L5, and midthigh in women and at L1, L2, and all 3 thigh slices in men. The SEE to predict SM changes ranged from 1.88 to 2.80 L in men and women.

With respect to AT, changes in slice areas were closely associated with total VAT and SAT volumes at all slices; correlations were stronger in men than in women. Best SAT estimates were obtained at MT+10 and L4 in women and men, respectively (Table 4). The SEE ranged from 0.94 to 3.43 L in both sexes. Changes in VAT areas correlated best with changes at L1–L2 (women) and L2–L3 (men) with a total SEE range of 0.29–0.88 L. Compared with cross-sectional data, the respective correlations were weaker in the longitudinal study (Tables 2 and 4).

**DISCUSSION**

Previous studies addressed the values of single MRI slice areas to estimate whole-body SM (3, 20) and AT (3–5, 9–15). Different reference slices were described that resulted in different slice locations for each tissue. To our knowledge, the current study is the first to systematically determine the best and joint single slice to estimate SM, SAT, and VAT in healthy adults to replace whole-body MRI and, thus, simplify the MRI protocol. In our cross-sectional data, L3 was shown as the reference slice to assess SM and AT in both sexes. Although
areas at L3 did not show the closest associations with all individual whole-body volumes (except for SM in women), areas at L3 were the best tradeoffs (Table 2, Figure 2).

**SM**

Best estimates for SM were shown at the thigh (women: MT +10; men: MT –10). Although, in women, the correlation coefficient from the area at L3 varied significantly from the optimal area, in men, no differences were observed (Table 2). Nevertheless, the area at the thigh can be replaced by L3. In women, this is restricted because of the lesser explained variance of 69.2% by L3 compared with the explained variance by MT+10 (85.5%). Our best slice estimates are in line with data of Lee et al. (20) who investigated total SM estimates from single-slice areas at the thigh and abdomen (L4–L5). In the study of Lee et al. (20), the thigh was the best predictor of whole-body SM volume. However, there was also a strong correlation between the area at L4–L5 and whole-body SM. Moreover, Shen et al. (3) examined the association between the SM area of a single MRI scan at lumbar region and total SM volume measured by using MRI in 328 healthy volunteers. The authors showed the closest association between total SM and the slice area at ~5 cm above L4–L5. Because this location is comparable with our reference at L3, the data also support our results when data obtained at the thigh were excluded.

Longitudinally, our correlations became weaker, and significant associations between changes of total SM and slice areas became less frequent (Table 4). There is a lack of corresponding studies on MRI-derived changes in SM volume. To our knowledge, associations between changes of single SM areas and whole-body SM volume have not previously been assessed by using whole-body MRI data. This study observed a moderate accuracy of single-slice areas at L3–L4, L4–L5, and midthigh in women and a high accuracy at midthigh +10 cm in men to predict SM, thereby indicating the midthigh as a suitable reference slice to predict changes in total-body SM volumes.

**VAT**

Best estimates for VAT were obtained at L2 in men and at L3 in women (Table 2). The association between the optimal area and

### Table 3: Total tissue MRI volumes of the longitudinal study population (n = 48)

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Women</td>
<td>Men</td>
</tr>
<tr>
<td>n</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Body weight, kg</td>
<td>103.3 ± 22.52,3</td>
<td>89.8 ± 16.9</td>
</tr>
<tr>
<td>Total tissue MRI volume, L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMtotal</td>
<td>23.6 ± 4.23</td>
<td>30.8 ± 3.4</td>
</tr>
<tr>
<td>SMtrunk</td>
<td>8.2 ± 1.73</td>
<td>10.9 ± 1.3</td>
</tr>
<tr>
<td>SMlegs</td>
<td>12.5 ± 2.23</td>
<td>15.2 ± 1.5</td>
</tr>
<tr>
<td>SMtruncus</td>
<td>3.0 ± 0.53</td>
<td>4.6 ± 0.8</td>
</tr>
<tr>
<td>SATtotal</td>
<td>46.2 ± 15.03</td>
<td>20.4 ± 9.0</td>
</tr>
<tr>
<td>SATtrunk</td>
<td>22.1 ± 7.43</td>
<td>9.2 ± 5.1</td>
</tr>
<tr>
<td>SATtruncus</td>
<td>19.9 ± 6.93</td>
<td>8.8 ± 3.5</td>
</tr>
<tr>
<td>VATtotal</td>
<td>4.2 ± 1.43</td>
<td>2.4 ± 0.8</td>
</tr>
<tr>
<td>VATtruncus</td>
<td>2.7 ± 1.5</td>
<td>2.8 ± 2.5</td>
</tr>
<tr>
<td>VATtruncus</td>
<td>2.7 ± 1.5</td>
<td>2.8 ± 2.5</td>
</tr>
</tbody>
</table>

1SAT subcutaneous adipose tissue; SM skeletal muscle mass; VAT visceral adipose tissue.
2Mean ± SD (all such values).
3Significantly different from men, P < 0.05 (unpaired t test).
4Significant changes from baseline, P < 0.05 (paired t test).
whole-body VAT volume was significantly higher than for the reference area at L3 in men. However, the area at L3 had a high $R^2$, and no major difference in the $R^2$ of L2 was seen; thus, L3 also became an evident reference for VAT. As regards the optimal as well as reference slice areas of VAT, our results support some previous data that showed a strong correlation between VAT volumes and VAT areas at the upper lumbar spine (4, 11, 14, 15, 27). This result is in line with data on postmenopausal women, which showed the strongest correlation between the whole-body VAT volume and slice areas at L1–L2 as well as L3–L4 (27). Accordingly, Shen et al. (4) showed that tissue areas 10 and 5 cm above L4–L5 (in men and in women, respectively) had the strongest correlation with whole-body VAT.

Longitudinally, all correlations were weaker than cross-sectional data, but stronger associations in VAT than in SM and SAT were shown (Table 4). Nonetheless, in men, the accuracy was high, and when compared with women, men showed closer associations between whole-body VAT changes and changes in different areas (Table 4). Only a few authors previously compared changes in AT volumes with weight-loss associated changes in individual slice areas (14, 15, 27). Concerning changes in VAT, Kamel et al. (28) showed the best slice areas to estimate VAT changes 5–10 cm above L4–L5. This result supports data of Shen et al. (14), who investigated weight loss in overweight and obese subjects and showed equivalent slices to detect VAT changes. By contrast, our data showed the closest correlations between weight loss-associated changes in total VAT and slice-area changes at L1 to L2–L3 in men (14). Nonetheless, L3 is a good tradeoff to assess VAT changes in men and women.

SAT

Best estimates for SAT were obtained at L5 (women) and at L4–L5 (men) with only minor differences to all other strongly correlated slice areas (Table 2). Both optimal correlations were significant higher than for reference areas at L3 with only slight differences in $R^2$. Only a few authors assessed whole-body SAT by using a single slice (14, 15, 27). They showed high associations between single-slice areas at the lumbar region and whole-body SAT volume, with no impact on the slice location (14, 15, 27), in support of our findings.

Longitudinal data showed moderate to strong correlations between all SAT areas and the whole-body SAT volume in both sexes, whereas men showed closer associations (Table 4). For both men and women, these data are in line with a clinical trial of Shen et al. (14), who showed moderate associations between whole-body SAT volumes and all areas. No major differences between correlation coefficients were shown, even though all of these associations were weaker than those obtained cross-sectionally (14), which is in accordance with our findings in men. Women showed significant differences between the best correlation coefficient at MT+10 and all other coefficients (except at L4). Thus, for the estimation of total-body SAT volume, as a reference site, L3 is a good tradeoff in men but not in women.

**Study strengths and limitations**

To our knowledge, this is the first study to systematically assess SM, VAT, and SAT in a cross-sectional and longitudinal study protocol. Detailed whole-body composition was measured by using the gold-standard method of whole-body MRI to achieve a high accuracy. As for single scans, our study considered 2 different regions at the lumbar spine and thigh to find a reference slice for men and women to estimate SM, SAT, and VAT. The volumes were compared with optimal slice areas for each tissue and sex. A strong association of L3 areas and all tissue volumes was shown. With the use of longitudinal and cross-sectional data, the limited applicability of a single slice to replace the whole-body MRI became evident. Most previous studies in that area of research had addressed SAT and VAT only. The study sample was homogeneous with regard to ethnicity and age, including a high percentage of obese subjects (women: 28%; men: 25%). Our results were limited to healthy, middle-aged subjects. Thus, cross-sectional as well as longitudinal data may not be valid in obese, malnourished, or sarcopenic obese individuals. Also, there is a lack of data during weight gain.

### Table 4

Pearson correlations between changes of total tissue volumes of SM, SAT, and VAT and changes of single-slice areas

<table>
<thead>
<tr>
<th>Correlation coefficient ($r$)</th>
<th>L1</th>
<th>L1–L2</th>
<th>L2</th>
<th>L2–L3</th>
<th>L3</th>
<th>L3–L4</th>
<th>L4</th>
<th>L4–L5</th>
<th>L5</th>
<th>MT−10</th>
<th>MT</th>
<th>MT+10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Women (n = 24)</strong></td>
<td></td>
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<td></td>
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<tr>
<td>SM</td>
<td>0.377</td>
<td>0.014</td>
<td>0.068</td>
<td>0.320</td>
<td>0.380</td>
<td>0.613</td>
<td>0.304</td>
<td>0.448</td>
<td>0.266</td>
<td>0.047</td>
<td>0.500</td>
<td>0.234</td>
</tr>
<tr>
<td>SAT</td>
<td>0.791</td>
<td>0.777</td>
<td>0.658</td>
<td>0.657</td>
<td>0.684</td>
<td>0.786</td>
<td>0.843</td>
<td>0.712</td>
<td>0.761</td>
<td>0.555</td>
<td>0.636</td>
<td>0.913</td>
</tr>
<tr>
<td>VAT</td>
<td>0.525</td>
<td>0.589</td>
<td>0.011</td>
<td>0.768</td>
<td>0.605</td>
<td>0.528</td>
<td>0.682</td>
<td>0.759</td>
<td>0.679</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><strong>Men (n = 24)</strong></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>SM</td>
<td>0.466</td>
<td>0.359</td>
<td>0.476</td>
<td>0.308</td>
<td>0.118</td>
<td>0.129</td>
<td>0.166</td>
<td>0.072</td>
<td>0.235</td>
<td>0.744</td>
<td>0.804</td>
<td>0.688</td>
</tr>
<tr>
<td>SAT</td>
<td>0.945</td>
<td>0.950</td>
<td>0.934</td>
<td>0.936</td>
<td>0.931</td>
<td>0.949</td>
<td>0.955</td>
<td>0.908</td>
<td>0.900</td>
<td>0.811</td>
<td>0.900</td>
<td>0.931</td>
</tr>
<tr>
<td>VAT</td>
<td>0.938</td>
<td>0.947</td>
<td>0.943</td>
<td>0.929</td>
<td>0.884</td>
<td>0.819</td>
<td>0.848</td>
<td>0.810</td>
<td>0.731</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

1All correlation coefficients were significant at $P < 0.05$. L, lumbar vertebra; MT, midthigh; MT−10, 10 cm proximally from the midthigh; MT+10, 10 cm distally from the midthigh; SAT, subcutaneous adipose tissue; SM, skeletal muscle; VAT, visceral adipose tissue.

2Correlation coefficient was significant at $P < 0.05$.

3Strongest correlation.

4Significantly different from the optimal correlation coefficient (within tissue and sex).

5Significantly different from the optimal correlation coefficient (within tissue and sex). $P < 0.05$ [method of Steiger (33)].

6Significantly different from correlation coefficient in men, $P < 0.05$ [Fisher’s Z transformation method (34)].
In conclusion, the current data suggest that a single-slice image at L3 is the best tradeoff to assess whole-body AT and SM volumes (an SEE of ~ 2.0 L for SM, ~ 0.5 L for VAT, and ~ 4.0 L for SAT). By contrast, L3 does not accurately reflect weight-loss-associated changes in all tissue volumes. Thus, there is no alternative to the use of whole-body MRI.

We thank Britta Jux, Klinik für Radiologische Diagnostik, University Hospital Schleswig Holstein Kiel, for help with MRI scanning. The authors’ responsibilities were as follows—LS and MJM: wrote the manuscript; LS, CG, and MJM: completed final data analyses; MP, BS, and LS: manually segmented organ and tissue areas; WB and AB-W: conducted the studies and performed all investigations; C-CG: performed MRI and dual-energy X-ray absorptiometry measurements; and AB-W and MJM: planned the study. None of the authors reported a conflict of interest related to the study.

REFERENCES