Differences of Subcutaneous Adipose Tissue Topography Between Type-2 Diabetic Men and Healthy Controls

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Men with noninsulin-dependent diabetes mellitus (type 2 DM) provide a different subcutaneous body fat distribution and a concentration of fatness on the upper trunk compared with healthy subjects. However, subcutaneous fat distribution is always measured in an inaccurate and/or very simplified way (e.g., by caliper), and to date, there exists no study reporting on the exact and complete subcutaneous adipose tissue distribution of type 2 DM men. A new optical device, the LIPOMETER, enables the noninvasive, quick, and safe determination of the thickness of subcutaneous adipose tissue layers at any given site of the human body. The specification of 15 evenly distributed body sites allows the precise measurement of subcutaneous body fat distribution, so-called subcutaneous adipose tissue topography (SAT-Top). SAT-Tops of 21 men with clinically proven type 2 DM (mean age of 57.5 ± 6.7 years) and 111 healthy controls of similar age (mean age 59.0 ± 5.4 years) were measured. In this paper, we describe the precise SAT-Top differences of these two groups and we present the multidimensional SAT-Top information condensed in a two-dimensional factor value plot. In type 2 DM men, especially in the upper trunk, SAT-Top is significantly increased (up to +50.7% at the neck) compared with their healthy controls. One hundred eleven of the 132 individuals (84.1%) are correctly classified (healthy or type 2 DM) by their subcutaneous fat pattern by stepwise discriminant analysis. Exp Biol Med 227:794–798, 2002

Key words: fat distribution; body composition; LIPOMETER; subcutaneous fat; metabolic disorders.

Obesity is a well-known risk factor for noninsulin-dependent diabetes mellitus (type 2 DM) in men. Some studies report on a relationship between type 2 DM and an excess of visceral adipose tissue (1, 2), whereas others also found correlations between body fat distribution and the disease (3, 2, 4), especially, a concentration of fatness on the upper part of the body (5, 6). Visceral adipose tissue can be assessed more or less accurate (e.g., by computed tomography [CT] of fat areas or simply by waist circumference), whereas subcutaneous fat distribution is always measured in an inaccurate (caliper) and/or very simplified way (CT cuts at two or three levels). Until today, there has been no study reporting on the complete subcutaneous adipose tissue (SAT) distribution of type 2 DM men.

The new optical device, LIPOMETER (EU patent number 0516251), enables a noninvasive, quick, precise, and safe determination of the thickness of SAT layers at any given site of the human body. The technical characteristics of the measurement system and a first validation of the results using CT as reference method have already been published (7–9). Fifteen well-defined body sites were specified (10), providing a SAT topography (SAT-Top) of the human body. SAT-Top includes the complete subcutaneous fat distribution information of a subject, which is like an individual "fingerprint."

Previously, we could show the enormous SAT-Top differences between women with type 2 DM and healthy controls (11–14), suggesting the LIPOMETER technique as a possible type 2 DM predictor. In the present paper, we want to present the exact and complete subcutaneous fat distribution of type 2 DM men, and the SAT-Top differences between type 2 DM men and healthy controls.

Methods

Diabetic Subjects. A group of 21 men with clinically overt type 2 DM was recruited at the university hospital of Graz to provide their SAT-Top values. Their descriptive statistics are presented in Table I.

Healthy Subjects. As a part of a "health and fitness check," SAT-Top was measured in 111 "healthy" men for comparison with type 2 DM men. Fasting glucose levels

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Table I. Descriptive Statistics (mean value ± SD [min – max]) of SAT-Top's of 21 Type 2 DM Men and 111 Healthy Controls of the Same Age Group

Personal parameters	Type 2 DM men (n = 21)	Healthy men (n = 111)	Significance of differences[a]
Age (years)	57.5 ± 6.7 (49.1–67.7)	59.0 ± 5.4 (50–69.7)	+n.s.[b]
Height (cm)	173.1 ± 4.7 (165–183)	173.7 ± 6.3 (161–197)	n.s.
Weight (kg)	86.4 ± 8.6 (65.8–106)	81.7 ± 10.2 (60–110)	n.s.
BMI	28.9 ± 3.0 (21.7–34.4)	27.1 ± 3.1 (19.2–39.7)	n.s.
Neck[c]	14.9 ± 3.6 (7.0–21.9)	9.9 ± 3.9 (2.4–29.1)	$P < 0.001$
Triceps	6.1 ± 2.2 (2.5–10.9)	5.0 ± 2.0 (1.6–11.6)	$P = 0.020$
Biceps	5.9 ± 2.0 (3.3–10.9)	4.0 ± 1.8 (1.4–14.2)	$P < 0.001$
Upper back	8.1 ± 2.1 (4.5–11.2)	5.7 ± 1.8 (2.4–10.0)	$P < 0.001$
Front chest	9.8 ± 2.7 (4.1–15.1)	7.5 ± 3.4 (1.5–18.3)	$P = 0.005$
Lateral chest	10.6 ± 3.8 (3.7–18.0)	8.7 ± 3.1 (2.0–17.7)	$P = 0.010$
Upper abdomen	11.9 ± 3.9 (6.3–20.5)	10.8 ± 3.8 (2.6–19.5)	n.s.
Lower abdomen	10.1 ± 2.1 (6.1–13.2)	9.5 ± 3.0 (2.1–19.5)	n.s.
Lower back	11.6 ± 2.5 (6.1–19.3)	9.1 ± 3.0 (1.8–17.2)	$P = 0.001$
Hip	11.3 ± 3.9 (6.0–21.8)	10.1 ± 3.7 (1.6–23.7)	n.s.
Front thigh	5.6 ± 1.7 (3.3–9.7)	4.5 ± 1.7 (1.1–10.2)	$P = 0.005$
Lateral thigh	4.5 ± 1.4 (3.1–9.7)	3.5 ± 1.8 (1.4–10.9)	$P < 0.001$[d]
Rear thigh	3.9 ± 1.2 (2.4–7.1)	3.0 ± 1.3 (1.4–7.3)	$P < 0.001$[d]
Inner thigh	8.4 ± 2.2 (4.7–13.5)	6.9 ± 2.5 (2.1–13.8)	$P = 0.013$
Calf	3.3 ± 0.8 (2.3–5.4)	2.7 ± 1.2 (1.0–9.5)	$P < 0.001$[d]
Upper trunk	43.4 ± 9.2 (19.5–55)	31.7 ± 10.0 (9.4–72.9)	$P < 0.001$
Arms	12.0 ± 3.9 (6.1–20.5)	8.9 ± 3.4 (3.0–25.8)	$P < 0.001$
Lower trunk	44.9 ± 7.4 (28.4–55.9)	39.6 ± 10.9 (11.2–70.8)	$P = 0.035$
Legs	25.8 ± 4.8 (16.6–35)	20.6 ± 6.8 (8.5–43.4)	$P = 0.001$
Total SAT	126.1 ± 18.4 (83.8–156)	100.9 ± 27.3 (38.5–200)	$P < 0.001$
Factor 1[e]	0.6 ± 0.6 (−0.8–1.4)	0.0 ± 0.7 (−1.6–2.1)	$P < 0.001$
Factor 2[f]	−0.8 ± 0.4 (−1.5– −0.3)	−1.0 ± 0.4 (−1.7–0.2)	n.s.

[a] By t test for independent samples.
[b] Not significant ($P > 0.05$).
[c] SAT thickness of 15 body sites in millimeters.
[d] By Mann-Whitney U test.
[e] Corresponds to trunk-SAT development.
[f] Corresponds to extremities-SAT development.

below 110 mg/dl were defined as nontype 2 DM. Only men who were not suffering from a chronic disease were selected for the "healthy" group. Their personal characteristics are also presented in Table I.

Measurement of SAT-Top. The new optical device, LIPOMETER, consists of light-emitting diodes as light sources and a photodetector. The light-emitting diodes illuminate the selected SAT layer, forming geometrically varying light patterns in succession. The photodiode detects the corresponding light intensities backscattered, which are amplified, digitized, and calculated into absolute values of SAT thickness (in millimeters). For validation of the LIPOMETER, CT was applied as reference method (7, 8). Notably, the LIPOMETER renders the absolute thickness of a SAT monolayer, which, for example, cannot be compared with the results of the well-known caliper, providing the thickness of a compressed skinfold including a double layer of skin.

To determine SAT-Top of an individual, the LIPOMETER is applied to measure the thickness (in millimters) of 15 specified SAT layers, which were previously depicted and described (10, 14). Measurements were performed on the right body side while subjects were standing. The body sites are evenly distributed over the whole body and are top-down sorted from neck to calf. The measurement results can be summarized as SAT-Top, describing precisely the subcutaneous fat distribution pattern of a subject (10).

Statistics. Statistical calculations were performed using SPSS for Windows (SPSS, Inc., Chicago, IL). The hypothesis of variables being normally distributed was tested by KOLMOGOROV-SMIRNOV test. Differences in the distributions of variables between healthy and type 2 DM men were tested by the Student's t test for independent samples (for normally distributed variables) and the Mann-Whitney U test (if variables were not normally distributed).

The 15 SAT-Top body sites, which are spread over the whole body, describe a detailed subcutaneous fat topography of a subject. Some of these sites are situated on the same body region (e.g., on the legs: sites 11–15) Consequently, they provide a similar fat development. To investigate the concluded SAT-Top information of complete body regions (e.g. upper trunk, arms, etc.), additional variables were calculated by summarizing the corresponding body sites:

- upper trunk = neck + upper back + front chest + lateral chest
- arms = triceps + biceps
- lower trunk = upper abdomen + lower abdomen + lower back + hip
- legs = front thigh + lateral thigh + rear thigh + inner thigh + calf

These additional variables might show more accurately the regional differences of SAT distribution between healthy and type 2 DM men. To give information about the total amount of subcutaneous fat in these two groups, all 15 SAT layer thicknesses were summarized to the variable total SAT.

SAT-Top values are partly highly intercorrelated. Therefore, the application of factor analysis (principal components method) is very useful to reduce this multidimensional SAT-Top information (15). Previously (10), two factors were extracted from a data set of 590 healthy subjects. Factor 1 corresponded to the trunk SAT-Top development, whereas factor 2 was related to SAT-Top of extremities. Results of this factor analysis for 590 healthy men (m_1: 20–30 years, . . . , m_5: 60–70 years) and women (w_1: 20–30 years, . . . , w_5: 60–70 years) divided into five age groups by decades were depicted in a two-dimensional factor value plot (10).

Furthermore, we added the SAT-Top information of 20 type 2 DM women to this plot for comparison with healthy women (14). This previously developed factor plot provided a helpful tool for visual SAT-Top description and comparison. Consequently, we want to base on it and increase its amount of information in the present paper, adding the group means of the 21 type 2 diabetic men and their healthy controls.

Discriminant analyses were performed on the body fat measurements obtained from the two groups to determine whether the SAT-Top approach distinguishes diabetic and healthy men, and to identify the measurements that distinguish them most clearly. Two analyses were performed: stepwise analysis of all 15 SAT-Top values: age, height, weight, factor 1, and factor 2; and analysis of all variables.

Results

The distributions of the 15 SAT layer thicknesses of healthy and type 2 DM men were tested by KOLMOGOROV-SMIRNOV test. The test provides no significant deviation from being normally distributed ($P > 0.05$) for most SAT-Top variables (only the body sites 12, 13, and 15 showed a $P < 0.05$ in healthy men), all summarized variables of the four body regions, and total SAT thickness. According to these results, the Student's t test for independent samples (in case of normally distributed variables) or the Mann-Whitney U test (otherwise) are applied to investigate the SAT layer differences between healthy and type 2 DM men.

Significant SAT-Top differences between the two groups are observed in all layers of the upper trunk (sites 1, and 4–6), the arms (sites 2 and 3), and the legs (sites 11–15), whereas most of the thicknesses of the middle part of the body, the abdominal region (sites 7, 8, and 10), are not significantly different (Table I). Generally, in case of statistical significance, type 2 DM men had thicker SAT layers (+0.6 to +5.0 mm) compared with their healthy controls (Fig. 1), whereby the greatest absolute difference (+5 mm) appears at the highest situated measurement point of the body, the neck. Figure 2 shows the distributions of this body site for both groups of men as box plots, whereby the measurement results of the type 2 DM men overlap less than 50% of the healthy cases. Slight absolute differences are observed on the legs.

Relative differences are presented in Figure 3, showing high percent values at the upper trunk (+22.7 to +50.7%) and the arms (+22.8 to +50.6%), and lower values at the legs (+21.6 to +28.3%). These results are confirmed more clearly by the summarized variables, providing great relative differences for upper trunk (+36.8%) and arms (+35.1%), small differences for lower trunk (+13.4%), and medium differences for legs (+24.9%), between the two groups of men (Table I). All summarized variables are normally distributed and show significant differences (Table I).

Furthermore, type 2 DM men have significantly more total subcutaneous fat thickness (+25%) compared with their healthy controls (Table I).

The results of factor analysis are presented in Figure 4, and the means of the two factors are shown in Table I. Factor 1 corresponds to subcutaneous trunk body fat development, whereas factor 2 is related to extremities SAT-Top. Only factor 1 is significantly different in the two groups (Table I). Type 2 DM men provide higher trunk SAT-Top and slightly higher (but not significant, $P = 0.076$) extrem-

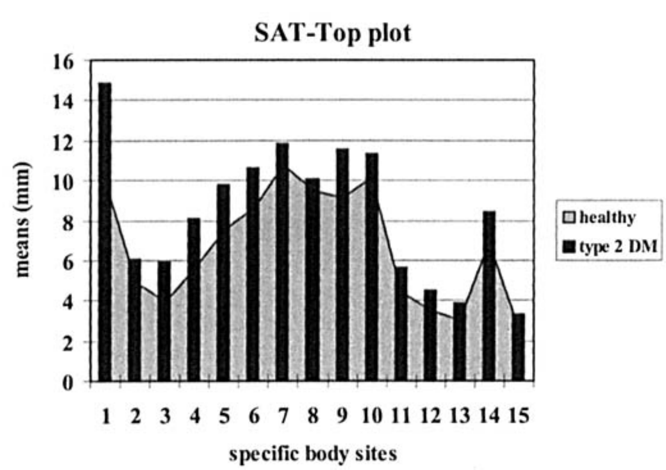

Figure 1. A SAT-Top plot for healthy and type 2 DM men. The body sites are sorted top-down: 1 through 6 are related to the upper trunk and arms, 7 through 10 are related to the lower trunk region, and 11 through 15 are related to the legs. Therefore, the SAT pattern of the different groups can be recognized easily. The highest deviation between healthy and type 2 DM men occurs at the body site 1-neck.

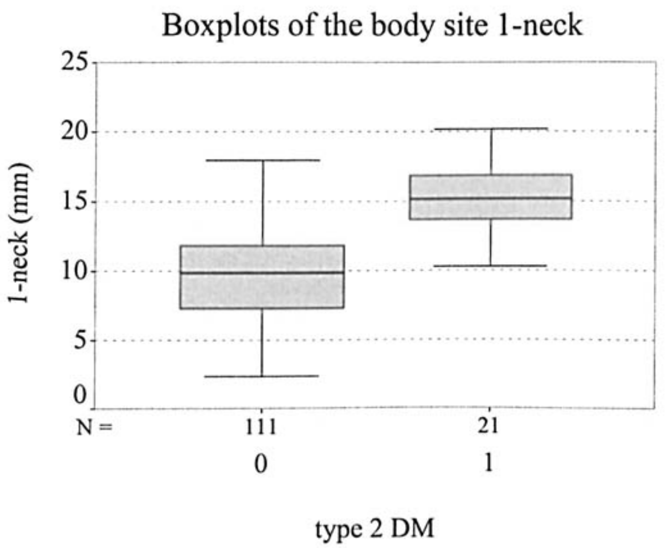

Figure 2. Boxplots to show the SAT thickness distribution of the body site 1-neck, which provides the greatest absolute difference between type 2 DM men (type 2 DM = 1) and healthy controls (type 2 DM = 0).

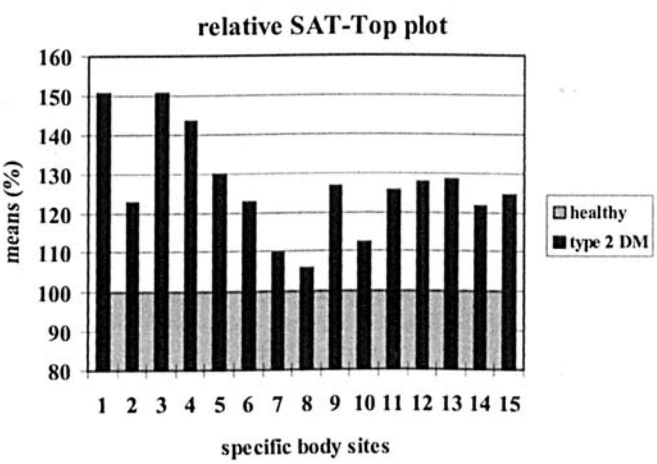

Figure 3. Relative SAT-Top plot. The means of healthy men are set to 100%. The deviation for the means of type 2 DM men body sites is especially high for the body sites 1-neck (+50.7%) and 3-biceps (+50.6%).

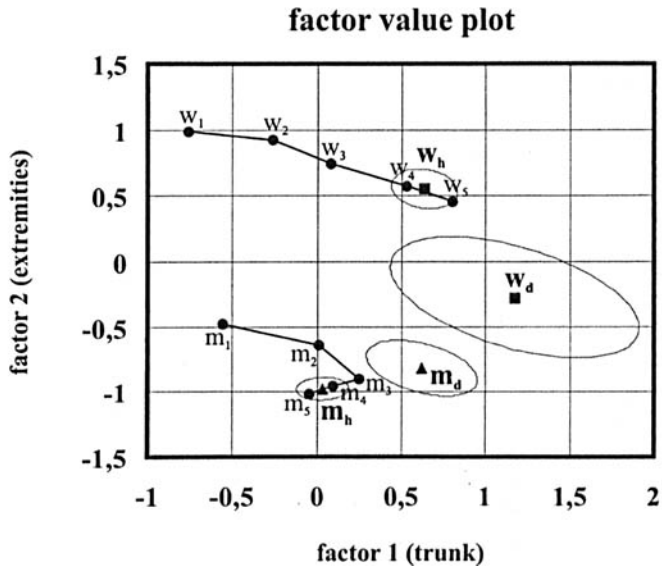

Figure 4. A factor value plot showing different age groups of healthy men (m_1: 20–30 years, . . . , m_5: 60–70 years) healthy women (w_1: 20–30 years, . . . , w_5: 60–70 years) (10), type 2 DM women (w_d), age-matched healthy women (w_h) for comparison with w_d in relation to the two factors (14), type 2 DM men (m_d), and healthy men (m_h) for comparison with m_d. A 95% confidence ellipse is presented for the means of w_d, w_h, m_d, and m_h. Factor 1 (x-coordinate) describes the subcutaneous trunk fat development of the different groups. Factor 1 values >0 correspond to a trunk fat development above average (e.g., diabetic subjects w_d and m_d), factor 1 values <0 show a trunk SAT development below average (e.g., healthy women [w_1] and men [m_1] of the age group 1: 20–30 years. Factor 2 values (y-coordinate) correspond to the extremities SAT development, e.g., healthy women ($w_1, \ldots,$ w_5, and w_h) provide thicker SAT values at the extremities, while healthy men ($m_1, \ldots\ldots,$ m_5. and m_h), diabetic women (w_d) and diabetic men (m_d) have an extremity SAT development below average.

ity SAT-Top than their healthy controls. These results are also depicted in Figure 4, where type 2 DM men (m_d) are compared with their healthy control group (m_h), with type 2 DM women (w_d), and with the different age groups of healthy men ($m_1, \ldots, m_5$) and healthy women ($w_1, \ldots, w_5$). In healthy men, trunk SAT-Top (factor 1) increases continuously through the first three age stages; afterward, it decreases slightly, and it develops even beyond the highest healthy age group (m_3: 40–50 years) in type 2 DM men. On the contrary, extremity SAT-Top of type 2 DM men is slightly higher compared with their healthy controls. Therefore, type 2 DM men are situated between the group of all healthy men and type 2 DM women.

Finally, all 15 SAT-Top values, age, height, weight, factor 1, and factor 2, are used as input for discriminant analysis. For 21 type 2 DM men and 111 healthy controls, the following classification results are provided: 84.1% of the 132 individuals are correctly classified by stepwise discriminant analysis (sensitivity = 81%; specificity = 84.7%), selecting the three body sites 1-neck, 4-upper back, and 8-lower abdomen for the discriminant function. The result is improved to 84.8% by the method of including all independent variables. Notably, out of all values presented to the discriminant analysis, only SAT-Top values were selected for the discriminant functions.

Discussion

Though obesity is a well-known risk factor for type 2 DM, to date, there exists only accurate studies concerning the visceral body fat, whereas papers investigating the role of body fat distribution have always had to fight the problem of inaccurate and/or very simplified measurement methods. The LIPOMETER technique enables quick, safe, and precise determination of the subcutaneous fat distribution of the human body, which allows for the presention of an exact SAT-Top description of men suffering from type 2 DM in this paper.

The group of men suffering from type 2 DM provided significantly more subcutaneous fat (+25%) than their healthy controls, though height, weight, and BMI were not significantly different. Previous papers presented healthy and type 2 DM subjects with comparable height, weight, and/or BMI showing a slightly but not significantly higher amount of subcutaneous fat in diabetics (2–4). These papers report on differences in the SAT distribution between healthy and type 2 DM men, which confirm our results.

Hyperandroid and android subjects were assigned a higher risk for type 2 DM by Vague (5), who presented pictures of extreme android and gynoid obese men and women, showing the stronger pronounced upper body obesity of the android fat pattern. Shuman *et al.* (2) found greater, but not significantly different thorax fat areas (by CT) in type 2 DM men compared with healthy controls, Mueller *et al.* (4) reported on significantly thicker subscapular skinfolds (by Lange caliper) in male diabetics, and Abate *et al.* (3) presented significantly higher midaxillary and subscapular skinfolds (by Lange caliper) for type 2 DM men, confirming our results of significantly higher SAT values at the body sites 4-upper back and 6-lateral chest. Notably, all of these results are measures for the android fat pattern. The advantage of our study seems to be the presentation of the complete SAT-Top for healthy and type 2 DM men, showing many of measurement points for each body region, which enables the recognition of the whole subcutaneous fat pattern and the finding of the most important body sites. Though all body sites of the upper trunk are significantly increased in type 2 DM men, the body site 1-neck (which is the highest situated body site) is the most important among them (Fig. 2; see also Figures 3–6 in Ref. 5), whereas 6-lateral chest seems to be situated a little bit too low on the body to be a good measure for the android fat pattern.

As we could previously show in type 2 DM women (14), SAT-Top results of the abdominal region are not of great importance. Furthermore, leg SAT-Top provides not much information in male diabetics, whereas in women, who normally have much more SAT on the legs than men, the reduction of leg fat in case of type 2 DM is of great importance.

Due to the more pronounced (upper) trunk obesity, the group of male type 2 DM patients is situated on the right side of healthy men and much closer to the group of type 2 DM women than their healthy controls (Fig. 4).

Mueller *et al.* (4), who measured five skinfold thicknesses (triceps, subscapular, waist, medial, and lateral calf), reported on a low discriminating power of the calculated skinfold discriminant function. Our stepwise discriminant analysis provided good results (84.1% correct classification), which even surpassed our findings for healthy and type 2 DM women (81% correct classification) (14).

We hope that these results obtained by the SAT-Top approach will contribute to the still ongoing search for type 2 DM predictors. It is worth emphasizing that the LIPOMETER measures only subcutaneous fat, providing good classification results even without the consideration of visceral fat. The additional use of common methods like WHR, BMI, and/or waist circumference, which provide information about the visceral fat, might even improve the classification results.

The LIPOMETER was developed as a research tool for clinical and preclinical studies. All authors are employed at the University and have no commercial interests concerning this device.

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