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A measure of obesity:
BMI versus subcutaneous fat patterns

Ein Messinstrument für Adipositas:
BMI versus Verteilung der subkutanen Fettmasse

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Danksagungen/Expression of thanks

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Zusammenfassung

EIN MESSINSTRUMENT FÜR ADIPOSITAS: BMI VERSUS VERTEILUNG DER SUBKUTANEN FETTMASSE

HINTERGRUND

Das BMI-Klassifikations-System wurde aus Durchschnittswerten der allgemeinen Bevölkerung entwickelt und scheint nicht spezifisch genug für Subgruppen wie Athleten und jüngeren Kollektiven zu sein. Verglichen mit der Allgemeinbevölkerung scheint die große Muskelmasse bei Athleten und jüngeren Personen zu einer Fehlklassifizierung zu führen. Aus diesem Grund scheint die Verteilung der subkutanen Fettmasse ein effizienterer Zugang zu sein, um den Ernährungsstatus zu erheben.

ZIELE

Die Ziele der vorliegenden Arbeit sind 1) die Beschreibung der Frequenz und thematischen Zuordnung der Verwendung des BMI in medizinischer Forschung und 2) die Analyse der Unterschiede in der Verteilung der subkutanen Fettmasse in Athleten und BMI-gematchten nicht aktiven Kontrollen.

METHODEN

Die Verteilung der subkutanen Fettmasse (SAT) wurde mit dem LIPOMETER in Millimetern an 15 definierten Stellen des Körpers vom Nacken bis zum Unterschenkel auf der rechten Körperseite gemessen. Die Gesamtheit der Messungen ergibt die Topografie des subkutanen Fettgewebes (SAT-Top). Alter, Größe, BMI und SAT-Top wurden bei 64 Männern (32 Athleten und 32 Kontrollen gematcht in Alter, Größe und BMI) und 42 Frauen (21 Athletinnen und 21 Kontrollen mit vergleichbarem Alter und vergleichbarer Größe) bestimmt. Die Athletinnen zeigten im Vergleich zu ihren Kontrollen ein signifikant höheres Gewicht und einen signifikant höheren BMI.

ERGEBNISSE

Obwohl die Athleten einen vergleichbaren BMI aufwiesen, ergab sich eine 50.3% niedrigere totale SAT Dicke (in mm: 35.9±12.3 (20.9-78.8)) im Vergleich zu den Kontrollen (in mm: 72.3±26.2 (32.4-131.8)) (p=0.001). Die Athletinnen zeigten

einen signifikant höheren BMI (p=0.016) und höheres Gewicht (p=0.011), trotzdem war ihre SAT-Dicke um 34.9% niedriger (in mm: 83.8±26.5 (33.9-145.6)) als die der Kontrollen (in mm: 128.8±28.7 (83.7-193.5)) (p=0.001).

ZUSAMMENFASSUNG

BMI als bekanntes und weit verbreitetes Messinstrument für Fettleibigkeit konnte nicht zwischen den Athleten/Athletinnen und ihren nicht sportlich aktiven Kontrollen unterscheiden (bei den Athletinnen ergaben sich sogar höhere BMI Werte), während sich bei der SAT-Top Bestimmung mittels Lipometer enorme Unterschiede zwischen den Gruppen ergaben. Aus den Ergebnissen erweist sich das Lipometer als bessere Messmethode zur Feststellung von Fettleibigkeit.

SCHLÜSSELWORTE

Body Composition, Body Mass Index, Fettmasse, Lipometer, Athleten

Abstract

A MEASURE OF OBESITY: BMI VERSUS SUBCUTANEOUS FAT PATTERNS

BACKGROUND

Compared with the general adult population, the influence of large muscle mass on BMI in athletes and young adults may misclassify these individuals as overweight and obese. Therefore, the use of subcutaneous adipose tissue topography (SAT-Top) may be a more effective measure than BMI in assessing obesity in athletes and young adults.

AIM

The purposes of this diploma thesis were 1) to describe the present use of the BMI in scientific fields, and 2) to analyse the differences of SAT-Top in athletes and BMI matched, not physically active controls.

METHODS

The optical device LIPOMETER was applied to measure the thickness of subcutaneous adipose tissue (SAT) in mm at 15 well-defined body sites distributed from neck to calf on the right body side. This set of measurement points defines a subcutaneous adipose tissue topography (SAT-Top). Age, height, weight, BMI and SAT-Top were determined in 64 men (32 athletes and 32 controls matched in age, height, weight and BMI) and 42 women (21 athletes and 21 controls with comparable age and height). Female athletes provided even significantly higher weight and BMI compared to their controls.

RESULTS

Though providing a comparable BMI, male athletes showed a 50.3% lower total SAT thickness (in mm: 35.9±12.3 (20.9-78.8)) compared to male controls (in mm: 72.3±26.2 (32.4-131.8)) (p=0.001). Female athletes even provided a significantly higher BMI (p=0.016) and weight (p=0.011), but nevertheless their total SAT thickness was 34.9% lower (in mm: 83.8±26.5 (33.9-145.6)) compared to controls (in mm: 128.8±28.7 (83.7-193.5)) (p=0.001).

CONCLUSION

BMI as a well-known and widespread measure of obesity cannot distinguish between our athletic and non-athletic subjects (in female athletes the BMI values were even higher), while SAT-Top provided enormous differences between these groups. Therefore, our results suggest the Lipometer SAT-Top as a better measure to determine body fat status.

KEYWORDS

Body Composition, Body Mass Index, Fat Mass, LIPOMETER, Athletes

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Glossary and acronyms

The following abbreviations are used in this diploma thesis:

ACSM	American College of Sports Medicine
BMI	Body Mass Index (kg/m²)
BC	Before Christ
CT	Computed Tomography
DXA	Dual energy X-ray absorptiometry
Fig.	Figure
kg	Kilogram
m	Meter
max	Maximum
min	Minimum
NIC	Newly industrializing country
n.s.	Not significant
p	Significance level
r	Correlation coefficient
SAT	Subcutaneous adipose tissue
SAT-Top	Subcutaneous adipose tissue topography
SD	Standard deviation
TBF	Total body fat
TBF%	Total body fat percentage
WHO	World Health Organization
X	Mean value

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1 Introduction

Obesity, which has developed into a world wide epidemic with an increasing tendency is a known risk factor for metabolic diseases. Therefore the scientific interest in this field is steadily increasing.

The Body Mass Index (BMI, kg/m²) is due to it's simple, fast and ubiquitous practicability a well-known and widespread measure of obesity. But how eligible is the BMI infact?

1.1 History of obesity

Going back to the roots of obesity and anthropometry (= the science of measurement of the human individual for the purpose of understanding the human physical variation(1)), the most of the human history corpulence was considered as a sign for good health and prosperity. Hippocrates already saw 400 BC that people who are very fat are tend to die earlier than those who are slender (2). Thus obesity is nothing new but not until the middle of the 19th century that the impact of obesity on people's health was perceived. The insurance industry began as recently as in the first decade of the 20th century to keep records of morbid complications and increased mortality because of obesity. (3, 4)

1.2 Definition of obesity

For a long time, the words obesus/obesitas and polysarcia (poly = many, sarcos = muscle) were used as synonyms. There was no clear definition and apparently no clear distinction between excess fat and excess muscle flesh. 1651 Bigg first used the word obesity in English, followed by Jaucourt who defines obesity 1765 in French as follows "Obesity is the amount of body fat, higher than needed by the humours and solid". (4, 5)

The current definition of obesity from the World Health Organization (WHO) is similar to the one of Jaucourt: "Obesity is a condition in which body fat stores are charged to an extent which impairs health. The disease in which excess body fat has accumulated in such an extent that health (increased mortality) may be adversely affected."(6) The WHO defines also a classification of BMI cut-off points and its risk to comorbidities (Tab. 1).

Table 1 BMI cut-off points and its risk to comorbidities defined by the WHO (7)

Classification	BMI [kg/m²]	Risk of comorbidities
Underweight	< 18.5	Low (but risk of other clinical problems increased)
Normal range	18.5 to 24.9	Average
Overweigth	≥ 25	
Pre-obese	25.0 to 29.9	Increased
Obese class I	30.0 to 34.9	Moderate
Obese class II	35.0 to 39.9	Severe
Obese class III	≥ 40.0	Very severe

1.3 Prevalence of obesity

During the last decades the prevalence of obesity increased explosivly and so the WHO declared it a global epidemic. Nowadays more than one billion people worldwide are overweight and about 300 million are obese. One of ten schoolchildren is overweight or obese these days. In Austria about 39% of the male population and 22% of the female population (18 to 65 years) is overweight and roughly 10% of those are obese. Prevalences for children and adolescents are a little lower. About 12% of the boys and 10% of the girls (6 to 15 years) are overweight and roughly 10% of those are obese. On the other hand 800 million people are suffering from hunger and its successions. Obesity is a “big” problem in developed and newly industrializing countries (NIC), first and especially in the United States of America. In those countries the economically weaker and less educated population is mostly affected. (8, 9)

1.4 History of BMI

In 1832 the polymath Lambert Adolphe Jacques Quetelet (Fig. 1) (1796-1874), born in Gent (Belgium), described the Quetelet Index as weight in kilograms divided by the square of the height in meters. He invented the Quetelet Index in the course of developing "social physics". In his book “A treatise on man and the development of his faculties”, he wrote „If we now compare fully developed and regularly built individuals so to assess the relationships that might exist between weight and height, we will find that the weights among developed subjects of different heights are approximately like the squares of the heights. It thus follows

that transversection including width and thickness is simply like a man's height". These words prove that he found the formula, but he did not propose it as a measure of body size or body fatness. His intent was defining the characteristics of an average man and to adjust the distribution around the norm. From 1831–1832 he directed what has been esteemed the first cross sectional study about children and newborns based on height and weight, and extended it to a study about adults. (3, 4)

Figure 1 Adolphe Quetelet (1796-1874) (3)

After the 2nd World War when actuaries reported the increased mortality of their overweight policyholders they saw need for a practical index of relative body weight and so the Quetelet Index was discovered again in the 1960s.

The fourth examination of the Framingham study (1954 to 1958) was one of the first studies to confirm the validity of the Quetelet Index. In 1972 Ancle Keys (1904-2004) confirmed the validity of the Quetelet Index and renamed it the Body Mass Index. Keys intended to use the BMI in population studies and not for individual diagnosis. (3, 10, 11)

In the early 20th century the term polysarcia was gradually replaced by obesity. It was James S. Garrow, a pioneer in body composition and obesity management, who proposed the Quetelet Index to become a measure of fatness in 1981. Further he proved that the BMI (Quetelet Index) correlates well with fat mass. The first health-related BMI classification system derives by Garrow et al. and was adopted in a modified form by the WHO.(7, 12)

1.5 The usage of BMI in scientific fields

Clinicians and researchers use the BMI, calculated as body mass in kilograms divided by height in meters squared, to classify adult obesity. BMI charts are also in use to determine the BMI. The chart displays the BMI as a function of weight (vertical axis) and height (horizontal axis) using different colours for several BMI categories or contour lines for different values of BMI (Fig. 2). For individuals under the age of 18, overweight is defined as a BMI over the 90th percentile and obesity over 97th percentile of age-specific BMI growth charts.

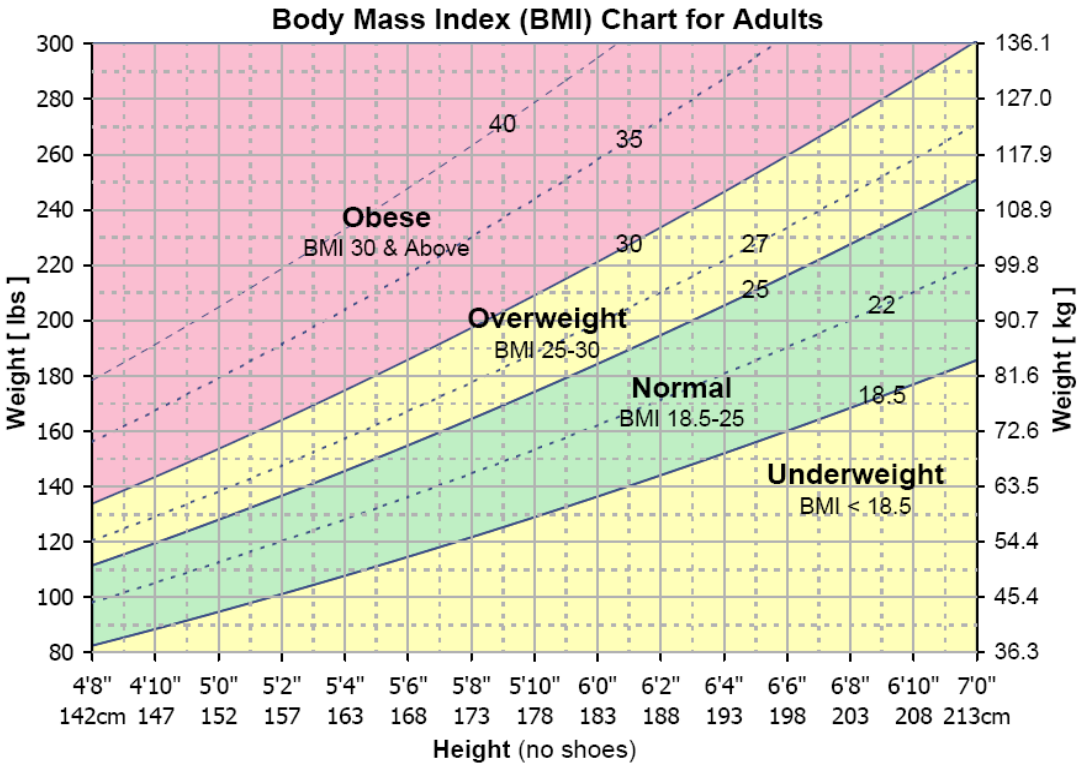

Figure 2 BMI chart for adults (13)

Due to it's fast, safe, simple and inexpensive handling the use of the BMI has become the most popular method to classify human weight. It is mostly combined with the waist circumference to assess the abdominal fat (WHO cut-off points see Tab. 2).

Aside the BMI there are actual no feasible alternative techniques for epidemiologic studies. Other methods to assess the body composition frequently lack precision and reproducibility (calliper techniques), entail the risk of radiation exposure (computed tomography (CT), dual energy X-ray absorptiometry (DXA)), are

inconvenient and time-consuming for the patient (hydrodensitometry) and/or are expensive (nuclear magnetic resonance, CT, air displacement plethysmography) (14). The Lipometer offers a new practical approach to measure the fatmass (a detailed description is given below).

Table 2 WHO cut off points for Waist circumference and its risk to comorbidities (7)

waist circumference [cm]	risk of comorbidities	
	increased	severe
men	94	102
women	80	88

Since James S. Garrow proposed the BMI as a measure of fatness in 1981, the number of publications using the BMI has continuously risen over the years (Fig. 3). The search term ”Body Mass Index” in the database “Web of Science” shows more than 60.000 matches (search date: August 2009).

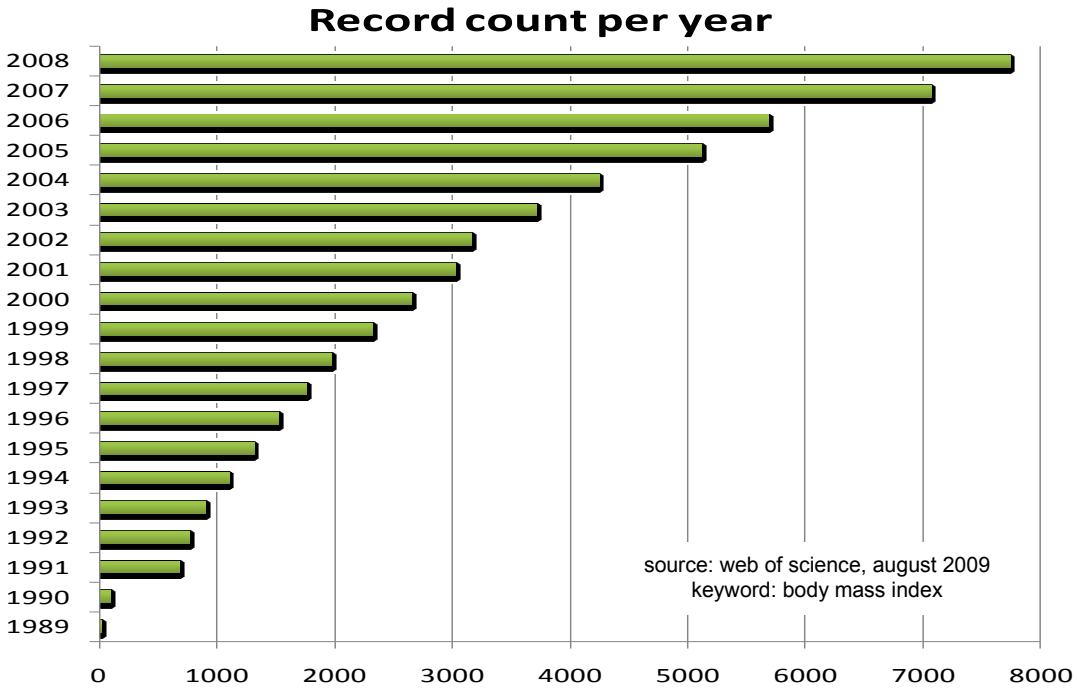

Figure 3 The annual world wide published papers using the BMI (from 1989 to 2008)

Worldwide more than 60.000 publications from different scientific fields are applying the BMI in their work. Ahead with more then 11.000 publications, is the endocrine and metabolism sector (Fig. 4). The adipose tissue as a endocrine organ that secretes a range of potently bioactive signalling molecules (e.g. leptin, resistin, interleukin-6, oestrogen,…) is a hot topic in the current research (15).

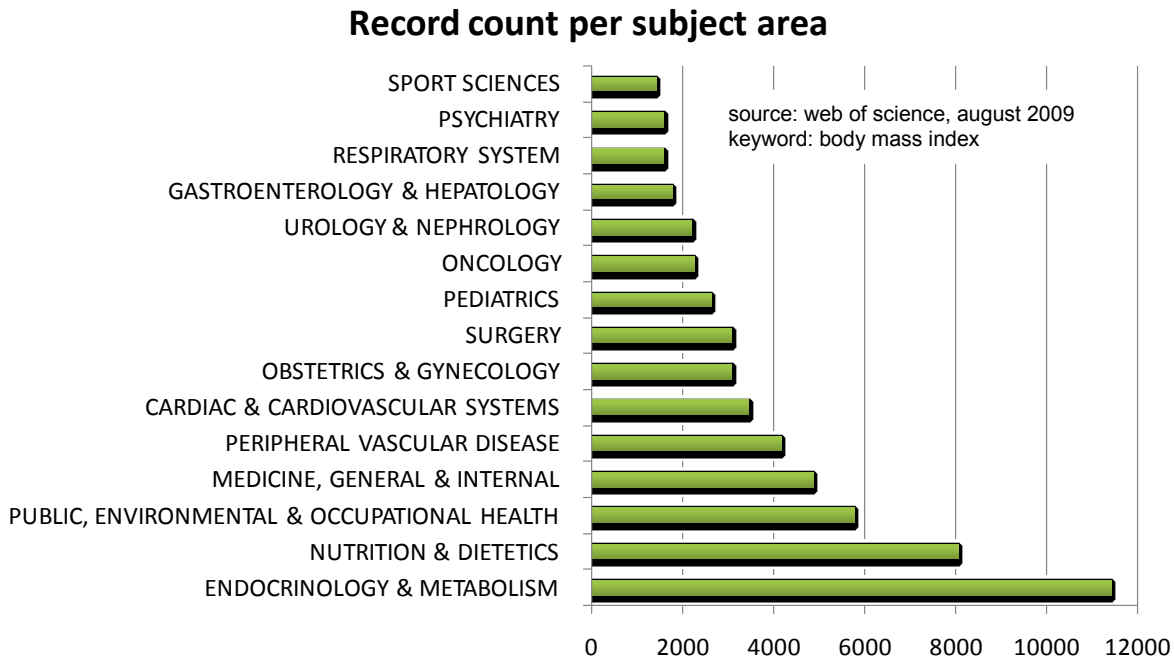

Figure 4 The fifteen top-rated subject areas using the BMI in their publications (from 1989 to 2008)

In Figure 5 the worldwide scientific use of the BMI becomes evident. Nearly 40% (~ 22.500 publications) of the publications are published in the United States of America. The german-speaking countries Germany (3.206 publications), Switzerland (950 publications) and Austria (630 publications) are ranked on the 11th, the 16th and respectively on the 26th place of this statistic.

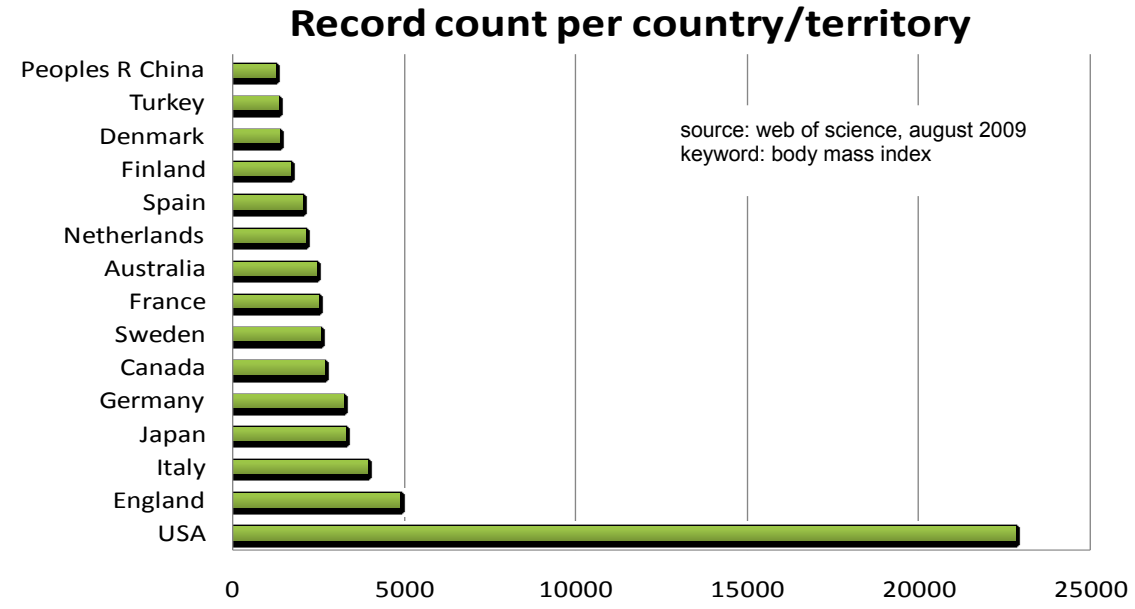

Figure 5 The fifteen top-rated publishing countries using the BMI in their papers (from 1989 to 2008)

1.6 BMI and disease

The BMI (kg/m²) exhibits a somewhat higher yet still moderate association with body fat and disease risk than estimates based simply on stature and body mass. As the BMI increases throughout the range of moderate and severe overweight, so also does risk increase for cardiovascular complication, certain cancers, diabetes, Alzheimer's disease, gallstones, sleep apnoea, osteoarthritis and renal disease (16-18).

1.7 BMI and body fat

Large population studies have illustrated that the BMI is related to morbidity and mortality. However, no subsequent large studies have confirmed these relation with Total Body Fat Percent (TBF%). Although BMI is correlated (r = 0.60-0.82) with TBF% (19), there is a lack of research regarding the usefulness of BMI as a surrogate for TBF%, and their exact biological relationship remains unclear. The classification of obesity on the basis of TBF% has not been formally established.
In an attempt to address this problem, the American College of Sports Medicine (ACSM) has reported predicted TBF% values for BMI in males and females across different age groups (20). ACSM used data by Gallagher and colleagues (21), who developed multiple regression models for predicting TBF% on the basis of BMI in 1626 subjects. In developing these equations, the authors used race, age and sex as predictor variables to help explain the model. Their results state that 20% TBF (in men) and 33% TBF (in women) are acceptable cut points for overfatness corresponding to a BMI of 25 kg/m^2 in young African American and white adults (ages 20-39). The predicted percentage body fat for young white adults with a BMI < 18.5 kg/m^2 was 8% TBF (in men) and 21% TBF (in women).

1.8 Limitations of BMI

The BMI classification system is derived from cut points obtained from the general adult population and may not be specific to subgroups such as physically active individuals (e.g. athletes) and young physically inactive individuals. Also under conditions such as infancy, ageing, racial differences and special clinical circumstances the BMI can provide misleading information about the body fat content due to the different proportion of lean body mass and hydration status in these subgroups.

Compared with the general adult population, the influence of large muscle mass on the BMI in athletes and young adults may misclassify these individuals as overweight and obese. In fact the excess adipose tissue is the cause of the comorbid conditions and not the excess weight. Therefore, the use of TBF% and subcutaneous fat patterns may be more effective than BMI in assessing fatness and obesity in physically active individuals and young adults. Furthermore the BMI as a surrogate measure of body fatness gives no insight into regional body fat distribution.

The computerized optical device, named the Lipometer (Moeller Messtechnik, Graz, EU patent number 0516251), allows a non-invasive, quick, precise and safe determination of the thickness of subcutaneous adipose tissue (SAT) layers at any chosen site of the human body. The technical characteristics of the measurement system and a validation of the results using computerised tomography as reference method have already been published (22). Fifteen anatomically well-defined body sites (Fig. 6) were specified to standardise Lipometer measurements (14), providing a subcutaneous adipose tissue topography (SAT-Top). SAT-Top includes the complete subcutaneous fat distribution information of a subject. Previous results confirmed the importance of SAT-Top measurements in the fields of obesity, nutrition and metabolic disorders in children (23) and adults (24-26).

Despite the potential limitations of BMI, it is commonly used to assess fatness in young adults (27) and athletes (28). Therefore, it is critical to understand the accuracy of BMI as a measure of TBF% in these populations. However, to our knowledge, no study has assessed the relationship between BMI and SAT-Top in young athletes and nonathletes.

Therefore, the purposes of this study were: 1) to describe the relationship between BMI and SAT-Top of young athletes and nonathletes and 2) to investigate the accuracy of the BMI categories as a measure of body fatness.

2 Material and Methods

2.1 Subjects

Participants were subsequently separated into 2 groups:

- ⇨ **athletes** (currently representing a sport and regularly training for at least 2 hr/day on 6 days/week)
- ⇨ **nonathletes** (not involved in a sport and not undertaking any regular exercise).

2.1.1 Male Subjects

Age, height, weight, BMI and SAT-Top were determined in 64 men, therefrom 32 athletes and 32 not physically active controls. They were matched in age, height, weight and BMI. Their descriptive characteristics are presented in Table 2.

2.1.2 Female Subjects

In order to measure their age, height, weight, SAT-Top and calculate their BMI 42 women were recruited. Therefrom 21 athletes and 21 not physically active controls with comparable age and height. Female athletes provided significantly higher weight and BMI compared to their controls. Their descriptive characteristics are presented in Table 3.

2.2 Anthropometric Measurements

2.2.1 Measurement of weight, height and calculation of BMI

Subjects wore light clothing (e.g. shorts and a light top) and no shoes during the measurements. Standing height was measured to the nearest 0.1 cm using a portable calibrated stadiometer (SECA®-220, Hamburg, Germany). Body mass was measured to the nearest 0.01kg using calibrated electronic scales (Soehnle® 7700, Murrhardt, Germany), BMI was calculated as body mass (kg) divided by height (m) squared.

2.2.2 Measurement of SAT-Top

The optical Lipometer device was applied to measure the thickness of SAT in millimetres at 15 well-defined body sites (Fig. 6) distributed from neck to calf. Measurements were performed on the right body side, while subjects were in an upright standing position. This set of measurement points defines the subcutaneous adipose tissue topography (SAT-Top) of each subject (29). The complete SAT-Top measurement cycle of one subject lasts about two minutes.

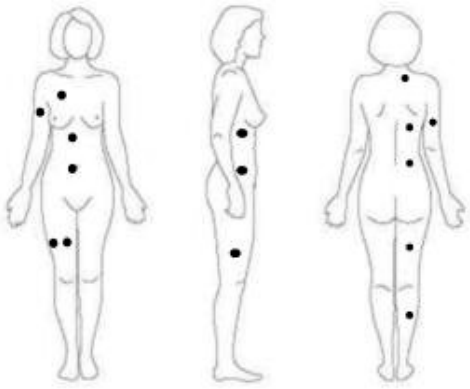

Figure 6 The fifteen body sites used for the SAT-Top (30)

2.3 Statistics

Statistical calculations were performed by SPSS for Windows (version 16.0). The hypothesis of variables being normally distributed was tested by the Shapiro-Wilk test and Kolmogorov-Smirnov test. Differences in the distributions of variables between athletes and nonathlete controls were tested by Student's t-test for independent samples (if normally distributed variables) and Mann-Whitney U test for independent samples (if variables were not normally distributed).

The 15 SAT-Top body sites, which are spread over the whole body, describe a detailed SAT-Top of the measured subject. Some of these sites are situated on the same body region (e.g., on the arms: triceps, biceps). Consequently, they provide a similar fat development.

To investigate the summed SAT-Top information of complete body regions (e.g. arms, trunk, etc.), additional variables were calculated by summarizing the corresponding body sites:

- ⇨ **Arms** = biceps + triceps
- ⇨ **Trunk** = neck + upper back + lateral chest + front chest
- ⇨ **Abdomen** = upper abdomen + lower abdomen + lower back + hip
- ⇨ **Legs** = front thigh + lateral thigh + rear thigh + inner thigh + calf

These additional variables were included as we speculate that they might show more accurately the regional differences of SAT distribution between athletes and nonathletes. To give information about the total amount of subcutaneous fat in these two groups, all 15 SAT layer thicknesses were summed (Total SAT). Furthermore TBF% was calculated by equations using DXA as reference method (31).

For visual comparison of different SAT distributions, in athletes and nonathletes, a relative SAT-Top plot was constructed (32). For the relative SAT-Top plot the 15 SAT layer means of the nonathletes were set to 100 % and the SAT-Top means of the athletes were calculated as percentage values, showing the deviation from the nonathlete SAT pattern.

Discriminant analyses were performed on the body fat measurements obtained from males and females to determine whether the SAT-Top approach distinguishes athletes and nonathletes, and to identify the measurements that distinguish them most clearly (32).

A total of five analyses were performed:

1. Total SAT
2. TBF%
3. stepwise analysis of the four compartments (arms, trunk, abdomen, legs)
4. sum of the 15 body sites
5. sum of all these 21 variables

3 Results

Male athletes and nonathletes were similar in terms of age, height, weight and BMI. However, male athletes showed a 50.3% lower Total SAT thickness (Fig. 9 shown in the appendix) (in mm: 35.9±12.3 (20.9-78.8)) compared to male nonathletes (in mm: 72.3±26.2 (32.4-131.8)) ($p<0.001$). The SAT layer thickness at the 15 body sites from neck to calf were significantly less in the male athletes compared to the male nonathletes (Tab. 3, Fig. 7). This was also the case for the additional variables (four compartments, TBF%).

Even though the female athletes had a significantly higher BMI ($p=0.016$) and weight ($p=0.011$), their Total SAT thickness was 34.9% lower (Fig. 10 shown in the appendix) (in mm: 83.8±26.5 (33.9-145.6)) compared to their nonathlete counterparts (in mm: 128.8±28.7 (83.7-193.5)) ($p<0.001$). SAT at all measured body sites was significantly lower in the female athletes compared to the nonathletes except for the lower abdomen, hip and rear thigh (Tab. 4, Fig. 8 shown in the appendix).

Relative differences of the SAT-Top plot between the 15 body sites and the four compartments of the male and females are presented in Figure 11 and 12 (shown in the appendix). The greatest relative differences between athletes and nonathletes appear for both sexes at the following body sites: neck, upper back, front chest and lateral chest (Fig. 11 shown in the appendix). Since these are the body sites of the compartment trunk, the relative plot of the four compartments (Fig. 12 shown in the appendix) confirms these high differences at the trunk (male athletes 41%, female athletes 44% of the nonathlete group measurements). Also the other compartments, arms (male athletes 52%, female athletes 60%), abdomen (male athletes 53%, female athletes 75%) and legs (male athletes 52%, female athletes 71%) provide significantly lower percent values in the athlete groups. Between the male and female athletes the greatest differences appear at the compartments abdomen (difference 22%) and legs (difference 19%). At the two other compartments arms (8%) and trunk (3%) the differences are lower.

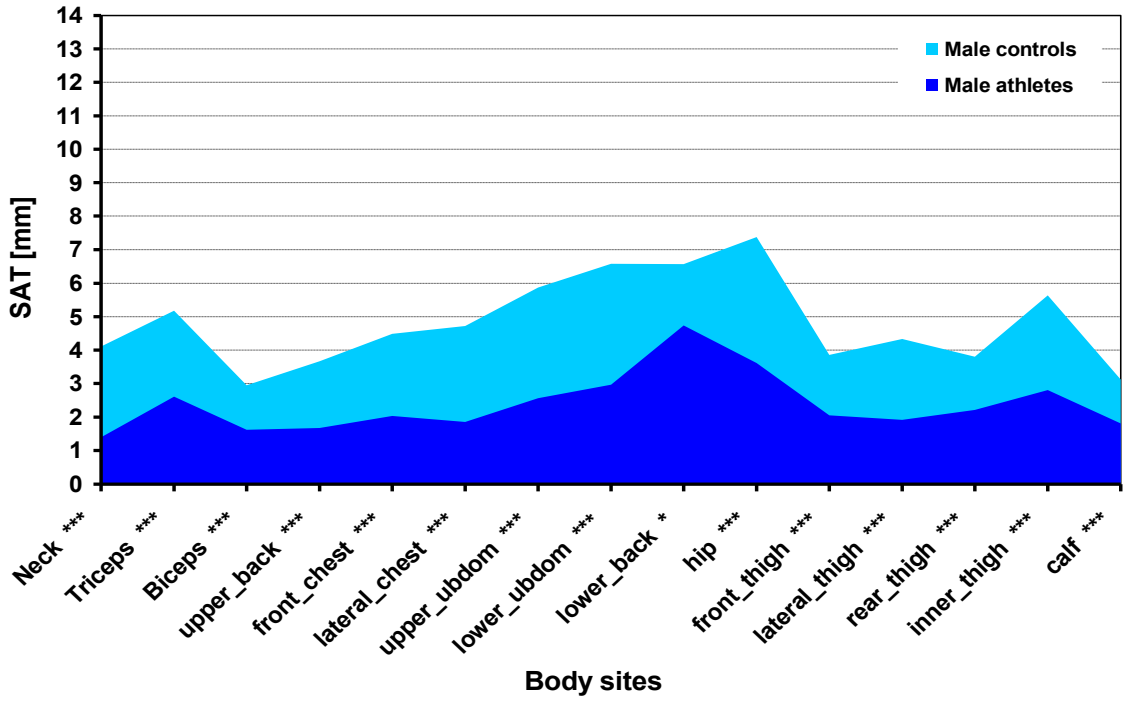

Figure 7 SAT-Top plot for male athletes and their not physically active controls, showing the SAT-differences of the fifteen top-down sorted body sites in millimetres (+ n.s., * p<0.05, ** p<0.01, *** p<0.001).

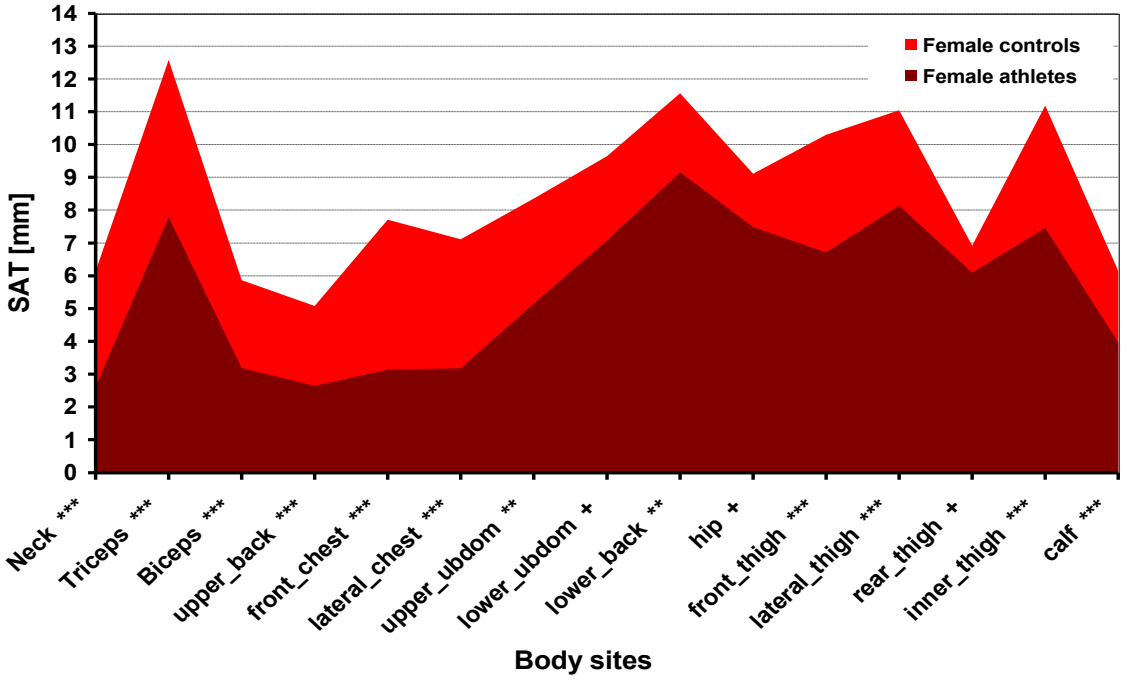

Figure 8 SAT-Top plot for female athletes and their not physically active controls, showing the SAT-differences of the fifteen top-down sorted body sites in millimetres (+ n.s., * p<0.05, ** p<0.01, *** p<0.001).

The results of the stepwise discriminant analysis for all male and female subjects are presented in Table 5 and Table 6 (shown in the appendix). Including several variables provided better classification results than including just a single variable: 81% of 64 males and 62% of 42 females were correctly classified as an athlete or nonathlete by using only TBF%. The correct classification was improved slightly when using Total SAT as the classification variable. Including all 21 variables correctly classified 89% of the male and 90% of the female subjects, and finally the best discrimination result for either group was achieved by including only the 15 SAT-Top body sites (correctly classified 89% of male and 93% females).

4 Discussion

In the present study we have shown that athletes and nonathletes of both sexes can be distinguished very clearly by their subcutaneous fat patterns. Despite comparable BMI across the male groups and even significantly higher BMI in the female athlete group, the measured SAT-Top values were significantly lower in the athletes compared to nonathletes in both groups. Male athletes showed a 50.3% and female athletes a 34.9% lower Total SAT thickness compared to nonathletes. Consequently, the results of our study illustrate that BMI is not an accurate measure of fatness in young athletes and nonathletes.

The ability of BMI to accurately reflect the amount of body fat across athletic and nonathletic populations has been assessed previously (33, 34). Nevill and colleagues report a 4.9-32% lower total skinfold thickness (measured by calliper) in male and 4.8-29.1% lower in female endurance, speed, strength and gambling athletes. Furthermore, when Witt and Bush examined the relationship between BMI and body fat in college athletes, the authors found that only 20% of women and 4% of men with BMI ≥ 25 kg/m^2 were above the 85th percentile for skinfold measurements. Ode and colleagues analysed the sensitivity, specificity and predictive values for BMI as a measure of body fatness measured via air displacement plethysmography (35) and found low sensitivity between BMI and bodyfat percentage for athletic populations.

Other investigators have examined the diagnostic ability of BMI in relation to TBF% in adults (19, 36-42). However, because of the lack of an established TBF% criterion for health status and the differences in study design, it is difficult to compare the results of our study with this previous research. Many of these studies used different methods for measuring TBF%, including DXA (36, 37, 39), skinfolds (38) and hydrodensitometry (19, 40, 42). The different TBF% cut points used to identify over fatness included 25% (19, 37), 30% (38, 40), 33% (42), 35% (39) and 38% (36) for females, and either 20% (19, 37) or 25% (38, 39, 42) for males. With the exception of one study that assessed postmenopausal women (36), each study assessed both males and females. The majority of studies included young, middle-aged and older adults (19, 37-40, 42), whereas an

additional study focused primarily on young and middle-aged adults (42). Within the postmenopausal women, BMI seemed to be a good diagnostic test for overfatness (36). However, the remaining research consistently indicated BMI has low sensitivity (0.06-0.60) and high specificity (0.86-1.0) as a measure of TBF% in both men and women (19, 37-40, 42).

The results of our current study suggest that BMI is not an accurate predictor of fatness in young athletes and nonathletes, because SAT-Top provided enormous differences between these groups. Probably due to a larger muscle mass among the male and female athletes, BMI incorrectly classified normal fat athletes as overfat. Therefore, our results suggest the subcutaneous fat patterns are a better screening tool to characterize fatness in physically active young people.

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6 Appendix

Table 3 Descriptive statistics [X ± SD (min – max)] of the two men groups matched by age, height, weight and BMI

Personal parameters	Male nonathletes (n = 32)	Male athletes (n = 32)	Significance of differences [1]
Age (years)	25.0 ± 3.7 (15.6-30.4)	25.0 ± 8.9 (15.0-47.7)	n.s. [2]
Height (cm)	178.7 ± 6.5 (167 -196)	179.7 ± 4.9 (172 -191)	n.s. [3]
Weight (kg)	72.0 ± 7.9 (59-95)	70.8 ± 6.4 (57-84)	n.s. [3]
BMI (kg/m²)	22.5 ± 1.2 (19.9-25.9)	21.9 ± 1.4 (19.3-24.9)	n.s. [3]
SAT-Top			
Neck	4.1 ± 2.0 (1.6-8.9)	1.4 ± 0.7 (0.7-4.6)	p < 0.001
Triceps	5.2 ± 2.3 (2.2-11.9)	2.6 ± 1.6 (0.9-7.9)	p < 0.001
Biceps	3.0 ± 1.0 (1.4-5.4)	1.6 ± 0.6 (0.9-3.5)	p < 0.001
Upper back	3.7 ± 1.3 (1.7-6.3)	1.7 ± 0.6 (0.9-2.9)	p < 0.001
Front chest	4.5 ± 2.2 (1.8-12.2)	2.0 ± 1.0 (1.1-5.5)	p < 0.001
Lateral chest	4.7 ± 2.5 (1.7-11.3)	1.9 ± 1.0 (0.8-6.0)	p < 0.001
Upper abdomen	5.9 ± 2.9 (2.1-12.8)	2.6 ± 1.9 (1.0-11.6)	p < 0.001
Lower abdomen	6.6 ± 3.4 (2.5-13.3)	3.0 ± 1.8 (0.9-9.2)	p < 0.001
Lower back	6.6 ± 2.6 (2.5-11.5)	4.7 ± 2.4 (1.1-10.1)	p < 0.01 [3]
Hip	7.4 ± 4.0 (2.3-16.9)	3.6 ± 2.5 (1.1-10.2)	p < 0.001
Front thigh	3.9 ± 2.0 (1.5-9.5)	2.1 ± 0.8 (0.7-4.5)	p < 0.001
Lateral thigh	4.3 ± 1.9 (2.0-11.1)	1.9 ± 0.8 (0.9-4.2)	p < 0.001
Rear thigh	3.8 ± 1.7 (1.7-8.3)	2.2 ± 1.2 (0.8-6.3)	p < 0.001
Inner thigh	5.6 ± 2.6 (2.0-13.9)	2.8 ± 1.1 (0.9-5.5)	p < 0.001
Calf	3.1 ± 1.7 (1.1-11.1)	1.8 ± 0.7 (0.9-3.6)	p < 0.001

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Compartments			
Arms	8.1 ± 3.1 (3.9-17.0)	4.2 ± 1.8 (2.1-9.5)	p < 0.001
Trunk	17.0 ± 6.9 (7.7-32.9)	7.0 ± 2.4 (4.3-16.6)	p < 0.001
Abdomen	26.4 ± 11.5 (9.5-45.9)	13.9 ± 7.3 (5.9-37.1)	p < 0.001
Legs	20.8 ± 7.4 (9.8-38.8)	10.8 ± 3.5 (5.9-22.6)	p < 0.001
Total SAT	72.3 ± 26.2 (32.4-131.8)	35.9 ± 12.3 (20.9-78.8)	p < 0.001
TBF%	16.0 ± 4.4 (9.7-29.8)	10.5 ± 2.7 (7.4-20.9)	p < 0.001

[1] By Mann-Whitney U test

[2] Not significant (P > 0.05)

[3] By t-test for independent samples

Table 4 Descriptive statistics [X ± SD (min – max)] of the two female groups with comparable age and height

Personal parameters	Female nonathletes (n = 21)	Female athletes (n = 21)	Significance of differences [1]
Age (years)	24.7 ± 2.4 (18.8-28.6)	25.0 ± 9.8 (15.9-46.7)	n.s. [2]
Height (cm)	165.4 ± 6.6 (152-179.2)	167.4 ± 5.6 (157-178)	n.s. [3]
Weight (kg)	55.4 ± 5.4 (47-68)	59.5 ± 5.9 (52-78)	$p < 0.05$
BMI (kg/m²)	20.2 ± 1.0 (19-23.3)	21.2 ± 1.6 (18.7-24.6)	$p < 0.05$
SAT-Top			
Neck	6.1 ± 2.7 (2.4-13.0)	2.6 ± 1.4 (1.0-5.5)	$p < 0.001$
Triceps	12.6 ± 3.8 (5.4-22.0)	7.8 ± 1.9 (1.9-11.1)	$p < 0.001$
Biceps	5.9 ± 2.4 (2.8-11.1)	3.2 ± 1.0 (1.7-4.9)	$p < 0.001$ [3]
Upper back	5.1 ± 1.7 (2.5-8.6)	2.6 ± 1.5 (1.0-7.6)	$p < 0.001$
Front chest	7.7 ± 3.4 (2.2-13.5)	3.1 ± 1.8 (1.1-8.5)	$p < 0.001$
Lateral chest	7.1 ± 2.9 (3.1-11.7)	3.2 ± 2.4 (0.9-9.8)	$p < 0.001$
Upper abdomen	8.4 ± 3.8 (2.8-16.4)	5.1 ± 3.2 (1.5-12.7)	$p < 0.01$
Lower abdomen	9.6 ± 4.2 (3.3-19.5)	7.1 ± 4.1 (1.8-16.0)	n.s. [3]
Lower back	11.6 ± 3.5 (6.1-20.0)	9.2 ± 3.5 (3.1-17.8)	$p < 0.05$ [3]
Hip	9.1 ± 4.6 (3.1-21.5)	7.5 ± 4.6 (1.4-17.1)	n.s. [3]
Front thigh	10.3 ± 2.8 (6.7-19.0)	6.7 ± 2.3 (2.1-10.8)	$p < 0.001$
Lateral thigh	11.0 ± 2.0 (6.7-15.7)	8.1 ± 3.2 (2.1-17.2)	$p < 0.01$ [3]
Rear thigh	6.9 ± 1.5 (3.1-9.2)	6.1 ± 2.2 (2.1-11.2)	n.s. [3]
Inner thigh	11.2 ± 2.0 (7.8-14.8)	7.5 ± 3.0 (2.3-11.7)	$p < 0.001$ [3]
Calf	6.2 ± 1.5 (3.5-8.9)	4.0 ± 1.6 (2.0-7.1)	$p < 0.001$ [3]

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Compartments			
Arms	18.4 ± 5.5 (8.2-33.1)	11.0 ± 2.5 (3.9-15.7)	p < 0.001 [3]
Trunk	26.0 ± 9.3 (11.4-41.6)	11.6 ± 5.6 (4.9-24.0)	p < 0.001
Abdomen	38.7 ± 13.1 (18.3-62.2)	28.9 ± 13.8 (11.1-58.3)	p < 0.05 [3]
Legs	45.6 ± 7.1 (33.3-61.3)	32.4 ± 10.5 (11.2-53.1)	p < 0.001 [3]
Total SAT	128.8 ± 28.7 (83.7-193.5)	83.8 ± 26.5 (33.9-145.6)	p < 0.001 [3]
TBF%	30.0 ± 3.3 (24.7-35.4)	27.1 ± 2.7 (21.1-30.4)	p < 0.01 [3]

[1] By Mann-Whitney U test

[2] Not significant (P > 0.05)

[3] By t-test for independent samples

Table 5 Results of the stepwise discriminant analysis for male athletes and nonathletes

Counted variables	Classified variables	Classification results in %	Included variables
15	Body sites	89	Upper back, lateral thigh
21	All variables [1]	89	Upper back, lateral thigh
4	Compartments [2]	84	Trunk
1	Total SAT	84	
1	TBF%	81	

[1] All variables = 15 body sites, 4 compartments, Total SAT, TBF%

[2] Compartments = arms, trunk, abdomen, legs

Table 6 Results of the stepwise discriminant analysis for female athletes and nonathletes

Counted variables	Classified variables	Classification results in %	Included variables
15	Body sites	93	Front chest, inner thigh, lower abdomen, upper back, calf
21	All variables [1]	90	Trunk, calf, abdomen, inner thigh
4	Compartments [2]	93	Trunk, legs, abdomen
1	Total SAT	74	
1	TBF%	62	

[1] All variables = 15 body sites, 4 compartments, Total SAT, TBF%

[2] Compartments = arms, trunk, abdomen, legs

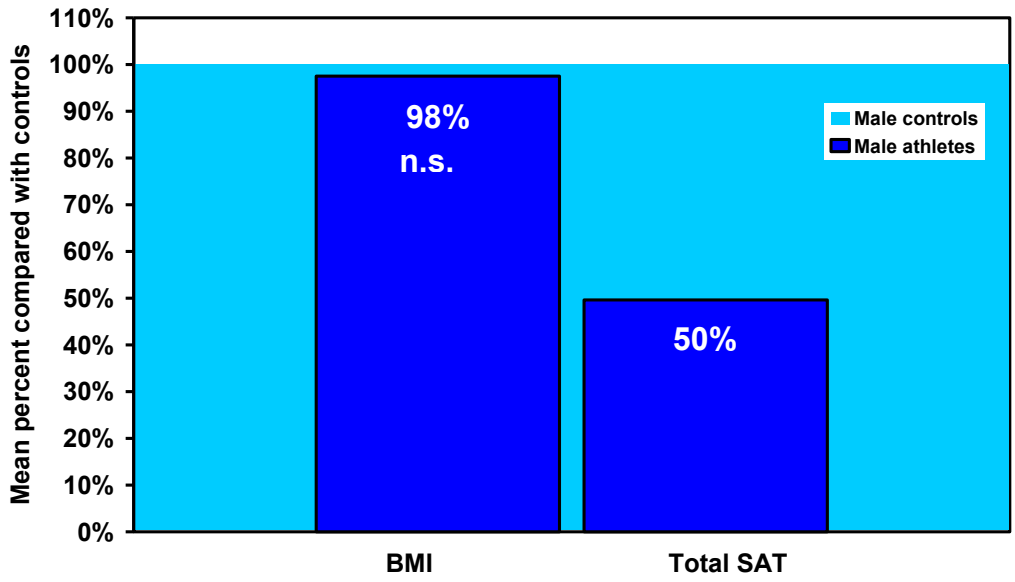

Figure 9 shows the deviation from the BMI and the Total SAT (in percentage) of male athletes and their not physically active controls (set to 100%).

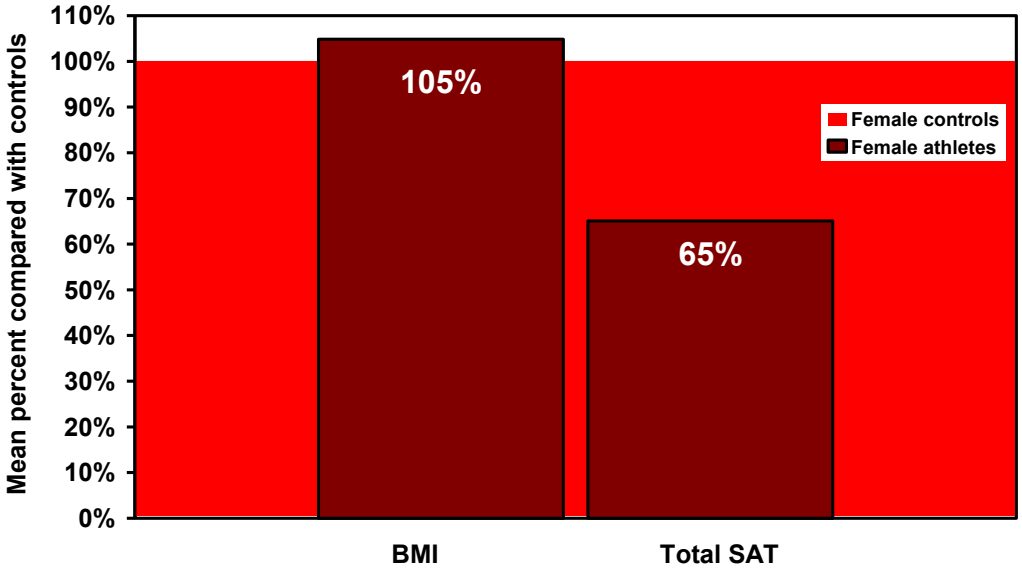

Figure 10 shows the deviation from the BMI and the Total SAT (in percentage) of female athletes and their not physically active controls (set to 100%).

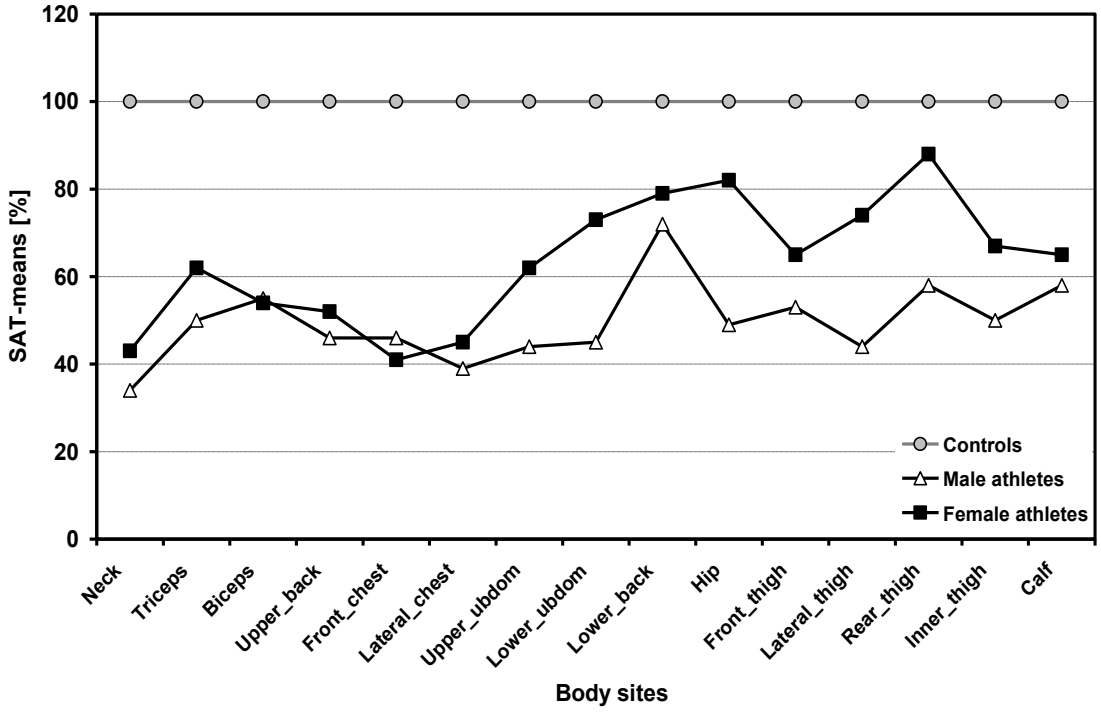

Figure 11 Relative SAT-Top plot of male athletes, female athletes and their not physically active controls (set to 100%), showing the deviation from the fat pattern of the not active group at all fifteen body sites (in percentage).

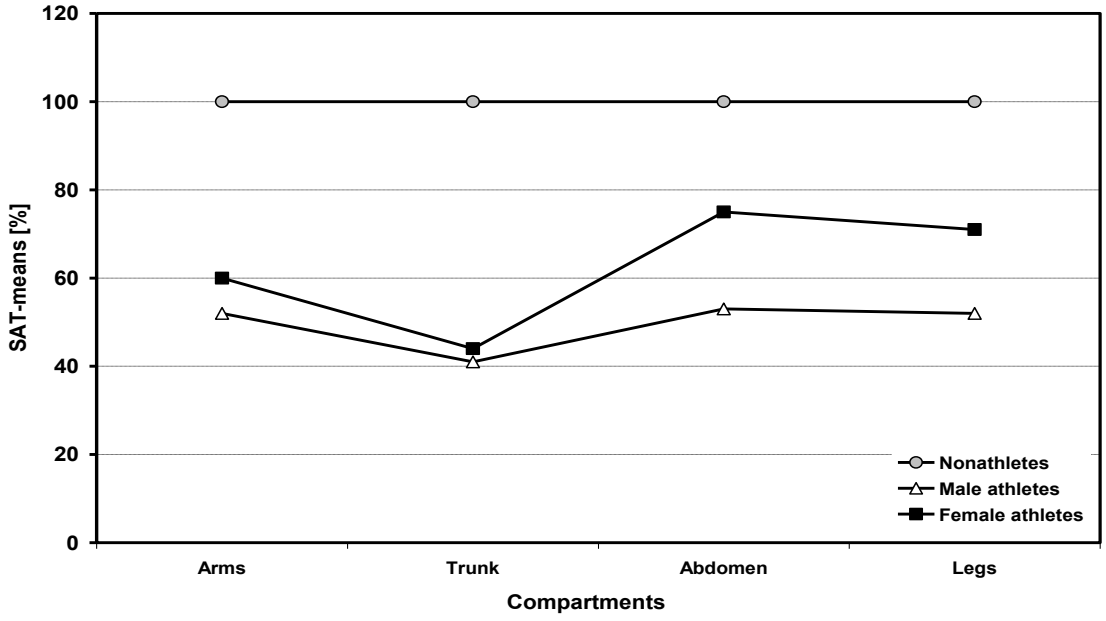

Figure 12 Relative SAT-Top plot of male athletes, female athletes and their not physically active controls (set to 100%), showing the deviation from the fat pattern of the not active group at four compartments (in percentage**).**

7 Curriculum vitae

Renate Kruschitz

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Phone: +43 660 52 95 913
Date of birth: 13th April 1980
Place of birth: Villach/Austria

GOAL:
To work in a demanding environment where I get first-class work experience while improving my medicine-based knowledge.

PERSONAL QUALITIES:
I am a good communicator and an open-minded person who likes working in a dedicated, precise and targeted way.

WORK EXPERIENCE:

July `05 – now **Dietician on a self-employed basis**
- be in charge of the MyLINE Program in two primary care settings
- research fellow at the Institute of Pathophysiology of the Medical University Graz
- conducted four times (2004-2007) a holiday camp for children who suffer from Phenylketonuria
- held lectures about nutritional themes for various associations
- worked among others for:
  the „Fond gesundes Österreich“,
  the umbrella association of the Austrian dieticians
  the Carinthian government
  the M & P advertising agency

Sept. `02 – Aug. 03' **Dietician**
Hospital for Orthopaedics and Rehabilitation centre
Warmbad-Villach, Austria
- given nutrition advice and created the diets for patients with various diseases
- held lectures about nutritional themes

July `99 – Sept. `99 **Ward assistent**
First aid station, Villach/Austria
- cleaned up, served food

EDUCATION

Oktober `03 – now medical student
Medical University, Graz, Austria

Okt. `99 – Sept. `02 BS in dietetics and nutrition
Academy for dietetics and nutrition, General Hospital, Vienna, Austria

Finished 1999 High school diploma
CHS – Centrum Humanberuflicher Schulen, Villach, Austria
- Majored in Accountancies, Business economics, Dietetics, English, Italian and Biochemistry

COURSES / OTHERS

Since 2005 singing education, Carolina Astanei, opera singer, Graz, Austria
February 2007 Erasmus Intensive Programme Combating Obesity: Strategies for Prevention and Intervention, Graz
November 2002 Diabetes schooling according to the Carinthian model
Medical association of Carinthia, Klagenfurt, Austria
February 1998 Schooling for Paramedic
Red Cross, Villach, Austria

COMPUTER SKILLS: windows applications, EWP, SPSS

LANGUAGES: German: Mother tongue
English: advanced
Italian: basics

INTERESTS: Nature, singing, sports

AWARDS:

2009 **GESKES-award** of the swiss society for clinical nutrition, within the framework of the 8th NUTRITION Congress, 4.-6. June 2009, Zürich, Switzerland.
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