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A Measure of Obesity: BMI versus Subcutaneous Fat Patterns in Young Athletes and Nonathletes

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A B S T R A C T

Although the body mass index (BMI, kg/m²) is widely used as a surrogate measure of adiposity, it is a measure of excess weight, rather than excess body fat, relative to height. The BMI classification system is derived from cut points obtained from the general 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 more effective than BMI in assessing obesity in physically active people and young adults. The purposes of this study were 1) to describe the relationship between the BMI and SAT-Top of young athletes and nonathletes, and 2) to determine the accuracy of the BMI as a measure of overweight. Height, weight, BMI and SAT-Top were determined in 64 males (25.0±6.7) and 42 females (24.8±7.0), who were subsequently separated into two even groups (athletes and nonathletes). The optical Lipometer device was applied to measure the thickness of subcutaneous adipose tissue (SAT). While BMI was similar, male athletes showed a 50.3% lower total SAT thickness compared to their male nonathlete controls. Even though female athletes had significantly higher BMI and weight scores, their total SAT thickness was 34.9% lower than their nonathlete controls. These results suggest subcutaneous fat patterns are a better screening tool to characterize fatness in physically active young people.

***Key words**: obesity, body mass index, subcutaneous fat, athletes, lipometer*

Introduction

Clinicians and researchers frequently use the Body mass index (BMI), calculated as body mass in kilograms divided by height in meters squared, to classify human obesity. This measure exhibits a somewhat higher yet still moderate association with body fat and disease risk than estimates based simply on stature and body mass. As 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[1–3].

Large population studies have illustrated that BMI is related to morbidity and mortality. However, no subsequent large studies have confirmed these relationships with Total Body Fat percent (TBF%). Although BMI is correlated (r=0.60–0.82) with TBF%[4], 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[5]. ACSM used data reported by Gallagher and colleagues[6], who developed multiple regression models for predicting TBF% on the basis of BMI in 1,626 subjects. In developing these

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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 Americans and white adults (ages 20-39). The prediced percentage body fat for young white adults with a BMI <18.5 kg/m^2 was 21% TBF (in women) and 8% TBF (in men).

The BMI classification system is derived from cut points obtained from the general population and may not be specific to subgroups such as physically active individuals (e.g. athletes) and young physically inactive individuals. Compared with the general adult population, the influence of a large muscle mass on BMI in athletes and young adults may misclassify these individuals as overweight and obese. Therefore, the hypothesis is that 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.

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. Previous results confirmed the importance of SAT-Top measurements in the fields of obesity, nutrition and metabolic disorders in children[7,8] and adults[9–11].

Despite the potential limitations of BMI, it is commonly used to assess fatness in young adults[12] and athletes[13]. 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 purpose of this study were twofold: 1) to describe the relationship between BMI and SAT-Top of young athletes and nonathletes, and 2) to investigate the accuracy of the BMI as a measure of overweight.

Subjects and Methods

Subjects

In a cross-sectional study design athletes and age-matched controls (non-athletes) were recruited to investigate BMI and subcutaneous adipose tissue differences. Sixty-four young male (age: 25.0±6.7 years), and 42 young female (age: 24.8±7.0 years) 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. To record the extent of training and competition load in individuals, structured questionnaires were used from which training volume in kilometer and hours per week was calculated.

Athletes

Swimmers and triathletes were recruited from triathlon and swimming clubs in Graz (Austria) and Christchurch (New Zealand). Athletes aged between 15 and 30 years with at least 3 years training experience, who were undertaking at least 2 hr/day, 6 days/week training and competition were recruited.

Nonathletes

The subjects of the non-athletic group were aged between 15 and 30 years, non-smokers, were currently taking no medication and performing no more than one hour of exercise per week. Descriptive characteristics of the groups are presented in Tables 1 and 2.

The procedures used in this study were in accordance with the Declaration of Helsinki and were approved by the local ethics committee (EK-number 19–054 ex 07/08).

Measurement of SAT-Top

The optical Lipometer device was applied to measure the thickness of SAT in millimeters at 15 well-defined body sites distributed from neck to calf. Measurements were performed on the right side of the body while subjects were in an upright standing position. This set of measurement points defines the SAT-Top of each subject[14,15]. The complete SAT-Top measurement cycle for one subject lasts about two minutes. The sensor head of the optical Lipometer device consists of a set of light emitting diodes as light sources and a photodetector. During measurement, this sensor head is held perpendicular to the selected body site. The diodes illuminate the SAT-layer, and the photodetector measures the corresponding light intensities back-scattered. The resulting light pattern values of a measured body site were calculated to absolute SAT layer thickness (in mm) using CT as the reference method. The measurement of agreement between CT and the Lipometer was a correlation coefficient of $r=0.99$, a regression line $y=0.97x+0.37$, and their was no systematic deviation of the Lipometer measurements from the CT results (Bias=0.0)[16,17].

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 the Kolmogorov-Smirnov test. Differences in the distributions of variables between athletes and nonathlete controls were tested by Student's t-test for independent samples (in case of normally distributed variables) and by 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

TABLE 1
DESCRIPTIVE STATISTICS (X±SD (MIN–MAX)) OF THE TWO MALE 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/m^2)	22.5±1.2 (19.9–25.9)	21.9±1.4 (19.3–24.9)	n.s.[3]
SAT-Top (mm)			
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
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

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 dual-energy x-ray absorptiometry (DXA) as reference method[18].

For visual comparison of different SAT distributions in athletes and nonathletes a relative SAT-Top plot was constructed[19]. 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[11]. 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 fifteen body sites and (5) sum of all these 21 variables together.

Results

Male athletes and nonathletes were similar in terms of age, height, weight and BMI, however, male athletes

TABLE 2
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 (mm)			
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]
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

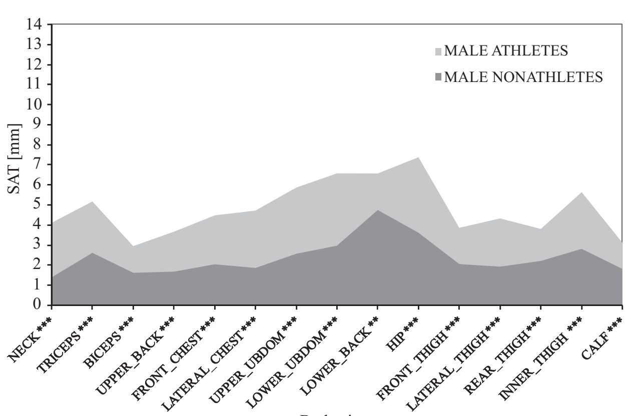

*Fig. 1. SAT-Top plot for male athletes and their nonathlete counterparts, showing the SAT-differences of the fifteen top-down sorted body sites in millimeters (+ n.s., * p<0.05, ** p<0.01, *** p<0.001).*

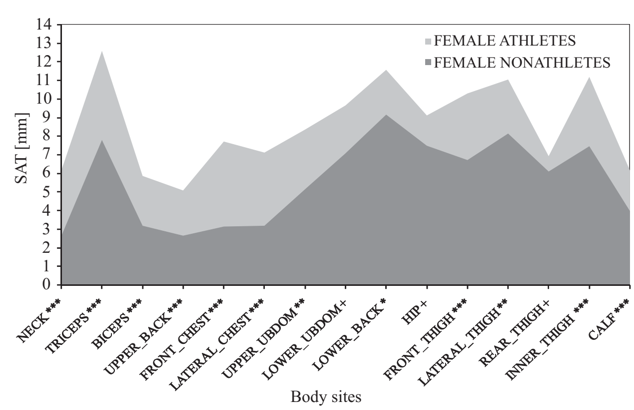

*Fig. 2. SAT-Top plot for female athletes and their nonathlete counterparts, showing the SAT-differences of the fifteen top--down sorted body sites in millimeters (+n.s., *p<0.05, **p<0.01, *** p<0.001).*

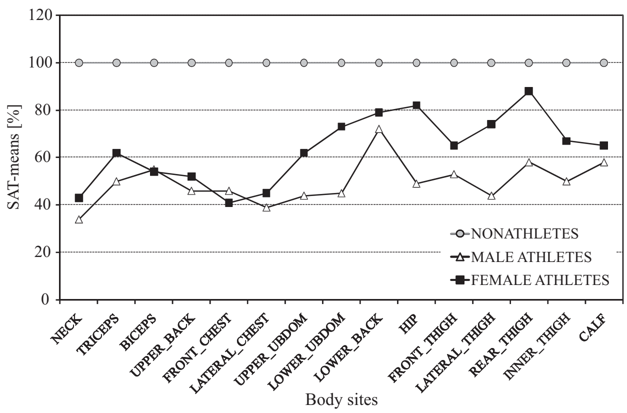

Fig. 3. Relative SAT-Top plot of male athletes, female athletes and their nonathlete counterparts (set to 100%), showing the deviation from the fat pattern of the not active group at all fifteen body sites (in percentage).

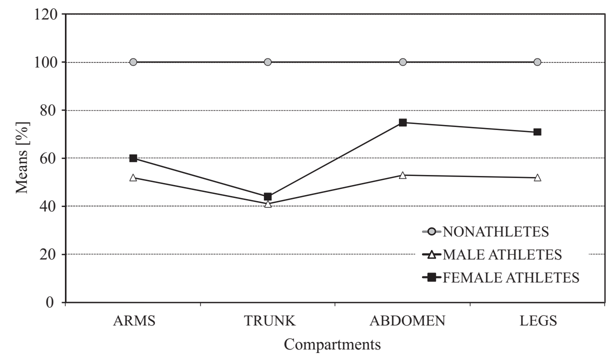

Fig. 4. Relative SAT-Top plot of male athletes, female athletes and their nonathlete counterparts (set to 100%), showing the deviation from the fat pattern of the not active group at four compartments (in percentage).

showed a 50.3% lower Total SAT thickness (35.9±12.3 mm) compared to male nonathletes (72.3±26.2 mm, 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 (Table 1, Figure 1). 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 (83.8±26.5 mm) compared to their nonathlete counterparts (128.8±28.7 mm, p<0.001). SAT at all measured body sites were significantly lower in the female athletes compared to the nonathletes except for the lower abdomen, hip and rear thigh (Table 2, Figure 2).

Relative differences between the 15 body sites and the four compartments of the male and females are presented in Figure 3 and 4. 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 (Figure 3). Since these are the body sites of the compartment trunk, the relative plot of the four compartments (Figure 4) confirms these high differences at the trunk (male athletes 41%, female athletes 44% of the nonathlete groups 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.

The results of the stepwise discriminant analysis for all male and female subjects are presented in Table 3 and Table 4. 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).

Discussion

In the present paper we have shown that young 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 mea-

TABLE 3
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 4
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

sured 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: Nevill and colleagues[20] report a 4.9–32% lower total skinfold thickness (measured by caliper) in male and 4.8–29.1% lower in female endurance, speed, strength and gambling athletes. Furthermore, when Witt and Bush[21] 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[22] analysed the sensitivity, specificity, and predictive values for BMI as a measure of body fatness measured via air displacement plethysmography and found low sensitivity between BMI and bodyfat percentage for athletic populations.

The results of our current study suggest that BMI is not an accurate predictor of overfatness 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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MJERA PRETILOSTI: INDEKS TJELESNE MASE NASUPROT OBRAZACA POTKOŽNE MASTI U MLADIH SPORTAŠA I NESPORTAŠA

SAŽETAK

Premda se indeks tjelesne mase (engl. body mass indeks – BMI, kg/m^2) široko rabi kao zamjenska mjera za adipoznost, to je zapravo više mjera za povišenu težinu nego za višak tjelesne masti relativne visini. BMI klasifikacijski sustav uspostavljen je na temelju podataka iz opće populacije. Utjecaj velike mišićne mase na BMI kod sportaša i mladih može krivo klasificirati ove osobe kao prekomjerno teške ili pretile. Stoga u procjeni pretilost fizički aktivnih osoba i mladih, uporaba topografije potkožnog adipoznog tkiva (SAT-Top) može biti puno učinkovitija od BMI. Cilj ovog istraživanja je da 1) opiše odnos između BMI i SAT-Top mladih sportaša i nesportaša te 2) da odredi točnost BMI kao mjere za prekomjernu težinu. Visina, težina, BMI i SAT-Top izmjereni su za 64 muškaraca (25,0±6,7) i 42 žene (24,8±7,0) koji su naknadno odijeljeni u dvije jednake grupe (sportaši i nesportaši). Za određivanje debljine potkožnog adipoznog tkiva (SAT) rabio se optički lipometar. Premda je BMI bio sličan, muški sportaši pokazali su 50,3% manje debljine ukupnog potkožnog adipoznog tkiva od nesportaške kontrole. Iako su ženski sportaši imali značajno viši BMI, njihova debljina ukupnog potkožnog adipoznog tkiva bila je 34,9% niža od njihovih nesportaških kontrola. Ovi rezultati pokazuju kako su obrasci u potkožnoj masti bolji pokazatelji debljine u fizički aktivnih mladih ljudi.