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Subcutaneous Adipose Tissue Topography (SAT-Top) Development in Children and Young Adults

Erwin Tafeit[1], Reinhard Möller[1], Toivo Jurimae[2], Karl Sudi[3] and Sandra Johanna Wallner[4]

[1] Institute of Physiological Chemistry, Center of Physiological Medicine, Medical University Graz, Graz, Austria
[2] Chair of Sport Pedagogy, Centre of Behavioural and Health Sciences, University of Tartu, Tartu, Estonia
[3] Institute for Sport Sciences, Karl-Franzens University Graz, Graz, Austria
[4] Institute of Pathophysiology, Centre of Molecular Medicine, Medical University Graz, Graz, Austria

A B S T R A C T

The importance of body composition measurements to elucidate the dynamics of related diseases in pediatrics is gaining recognition. The methods used should not expose subjects to high doses of radiation and require substantial cooperation. The Lipometer is a new optical device that enables the non-invasive, quick and safe determination of the thickness of subcutaneous adipose tissue (SAT) layers (in mm) at any site of the human body. The topographic specification of 15 evenly distributed body sites, which makes it possible to precisely measure subcutaneous body fat distribution, is called subcutaneous adipose tissue topography (SAT-Top). SAT-Top was determined in more than 1000 children and young adults between the ages of 7 and 21. In this paper we describe the SAT-Top development of these subjects through different age groups and the differences between male and female SAT-Top development in each age group. SAT layer profiles (medians of the 15 body sites) for boys and girls in age group 1 (7–9 yrs) show a very similar pattern for both sexes, followed by slightly decreasing SAT layer thicknesses in boys and increasing values in girls in the subsequent age groups. Between age group 3 (11–13 yrs) and age group 7 (19–21 yrs) male and female SAT-Top is significantly different. The discriminating power between male and female SAT-Top was investigated by stepwise discriminant analysis, which provided no significant results for age group 1 (7–9 yrs), about 73% correct classification for age group 2 (9–11 yrs) and 3 (11–13 yrs), 83% for age group 4 (13–15 yrs), and about 91–93% for the following age groups (15–21 yrs).It is known that SAT development is the same in both sexes until puberty, when girls gain relatively more fat mass than boys to reach a higher body-fat percentage as adults. This paper presents a precise description of SAT development in boys and girls from childhood to adolescence, which provides a basis for further investigations.

Key words: *subcutaneous fat distribution, body composition, lipometer*

Introduction

Interest in the field of pediatric body composition is growing because the study of changes in various compartments of fat helps to elucidate the dynamics of related health outcomes. There are different methods for assessing body composition in children: densitometry, 2H dilution, total body K, dual-energy x-ray absorptiometry (DXA), anthropometry and bioelectrical impedance analysis (BIA). Some of these methods are expensive, technically awkward and impractical for use in a field study. Exposure of pediatric subjets to high doses of radiation (computed tomography) should be avoided. DXA provides a minimal amount of ionizing radiation exposure that is equivalent to 1% of the radiation exposure from a chest X ray; however, the risks versus benefits of body composition assessment must be considered. Skinfold measurements have been recommended for the assessment of fat mass (FM) in children[1–4]. However, the accuracy of this field method in terms of measurements of FM depends on an appropriate prediction equation. Therefore, SAT topography in children seems to be an interesting approach. The optical device LIPOMETER (EU Pat.No. 0516251) provides non-invasive, quick, precise

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and safe measurements of subcutaneous adipose tissue (SAT) layer thicknesses at any site of the human body. Its technical characteristics and validation results using computed tomography as a reference method have been presented before[5–7].

Previous results[8–10] confirmed the importance of describing the subcutaneous fat distribution in the field of obesity and metabolic disorders of adults and during growth[11–13]. In the present paper, we focus on children and young adults: deviations from a »healthy« or non-obese SAT-Top pattern might have their roots in childhood. This period is a sensitive time for the development of characteristics, e.g. the well-known »masculinizing process« in the subcutaneous fat development of adults[14] that predisposes one to the chronic diseases of aging. As a first step, which provides a basis for further investigations in this field, SAT-Top was determined in more than 1000 children and young adults between the ages of 7 and 21. We present body composition as a function of age, analysing

1.) their SAT-Top development through different age groups
2.) the beginning of the sexual differentiation in the subcutaneous fat development of both sexes, and
3.) the differences between male and female SAT-Top development in each age group.

Materials and Methods

Healthy subjects

The participants and their parents were consented to the study after full explanation of the protocol by a physician. The procedures were in accordance with the Declaration of Helsinki and the local ethics committee recommendations.

Height was measured using a stadiometer (SECA®-220, Hamburg, Germany), and body weight was determined by a Soehnle® scale (Soehnle® 7700, Murrhardt, Germany). Height, weight and SAT-Top were measured in 1026 healthy boys and girls between the ages of 7 and 21, who were recruited in different schools, mainly from urban areas, and at university. This dataset was divided into seven age groups (group1: [7–9] yrs, group2: [9–11] yrs,..., group7: [19–21] yrs) for each sex[15–16].

Measurement of subcutaneous adipose tissue topography (SAT-Top)

To determine the thickness of a SAT layer (in mm), the sensor head of the LIPOMETER is held perpendicular to the measured body site. Light-emitting diodes illuminate this SAT layer and a photodiode measures the corresponding back-scattered light intensities. These light signals are converted into a SAT layer thickness[17].

SAT-Top consists of a complete cycle of 15 SAT layer thickness measurements (in mm) at specific body sites distributed evenly from neck to calf on the right side of the body, while the subject is in standing position (Figure 1). The time consumption is about two minutes for the SAT-Top determination of a person. The LIPOMETER is connected to a PC, which stores the data measured.

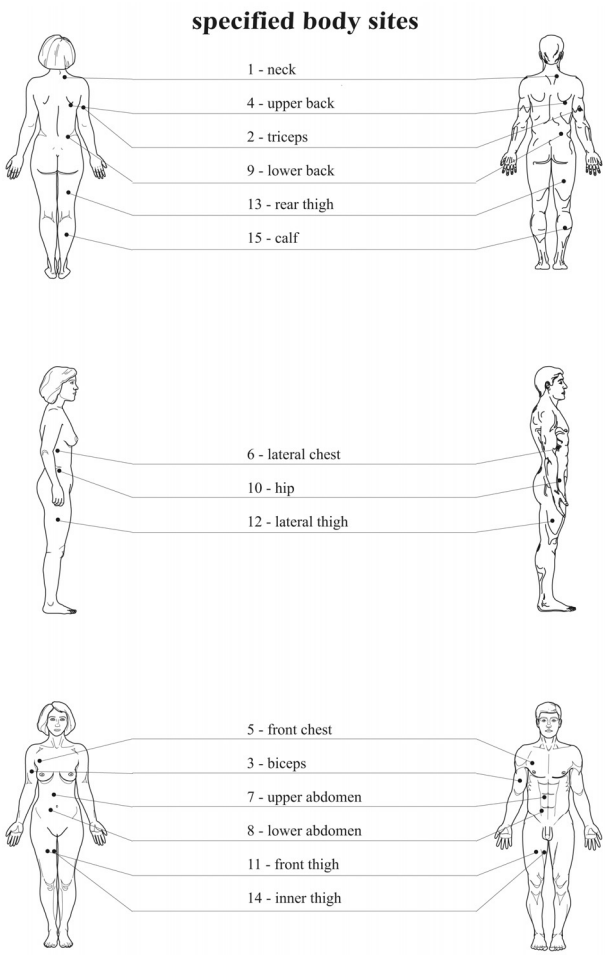


Fig. 1. Fifteen specific body sites for measuring the SAT-Top of the human body (Reprinted from Möller et al.[6]).

Statistics

Statistical calculations were performed by SPSS for WINDOWS. The hypothesis that the variables would be normally distributed was tested by the KOLMOGOROV-SMIRNOV test, in which a p-value < 0.05 was considered to be a significant deviation from normal distribution. Most of the 210 tested distributions (15 SAT-Top values * 7 age groups * 2 sexes) were non-normal, and thus the median and non-parametric tests, namely the Mann-Whitney U-test for two independent samples and the Kruskal-Wallis H-test for more than two independent samples, were applied to describe the distributions of SAT-Top values and test the significance of differences between them.

Finally, stepwise discriminant analysis was used to investigate the discriminating power between male and female SAT-Top in all age groups.

TABLE 1
DEMOGRAPHIC CHARACTERISTICS (MEAN±SD) OF 582 BOYS AND 444 GIRLS FOR SAT-Top MEASUREMENT

	Boys				
	Age group	N	Age (yrs)	Height (cm)	Weight (kg)
Group1:	[7–9] yrs	39	8.0±0.5	132.5±7.3	29.5±6.5
Group2:	[9–11] yrs	53	10.0±0.7	140.2±7.1	33.6±6.4
Group3:	[11–13] yrs	155	11.9±0.6	149.6±8.0	40.4±8.8
Group4:	[13–15] yrs	158	14.0±0.5	164.8±9.5	53.5±10.5
Group5:	[15–17] yrs	86	15.9±0.6	174.8±6.4	63.2±8.2
Group6:	[17–19] yrs	66	17.9±0.6	178.7±6.8	69.6±8.0
Group7:	[19–21] yrs	25	19.7±0.5	180.7±5.9	72.3±6.9
	Girls				
	Age group	N	Age (yrs)	Height (cm)	Weight (kg)
Group1:	[7–9] yrs	31	7.9±0.6	127.3±6.0	26.2±5.1
Group2:	[9–11] yrs	39	10.1±0.6	140.1±6.7	33.5±6.9
Group3:	[11–13] yrs	117	12.0±0.5	152.6±7.9	44.0±10.2
Group4:	[13–15] yrs	114	14.1±0.6	163.3±6.0	52.9±9.0
Group5:	[15–17] yrs	84	15.8±0.5	166.2±6.6	57.8±9.2
Group6:	[17–19] yrs	38	17.8±0.6	167.1±8.5	60.8±12.0
Group7:	[19–21] yrs	21	20.1±0.6	167.9±6.5	57.6±7.1

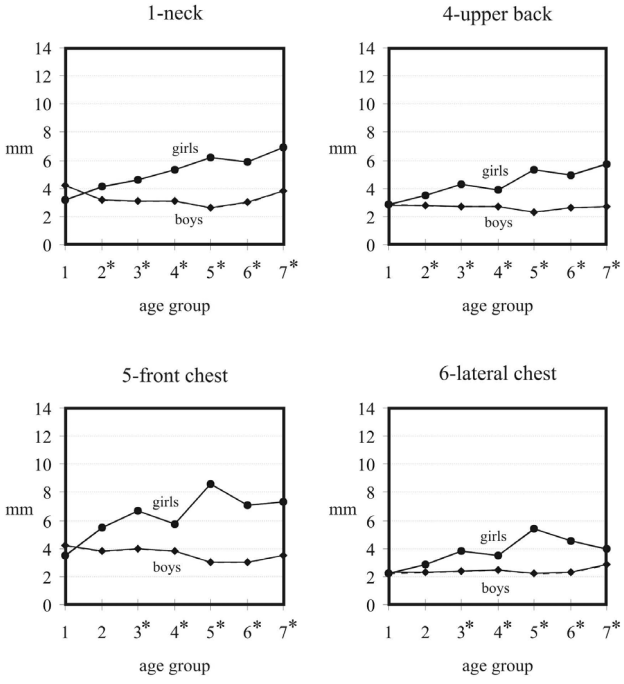


Fig. 2. Medians of upper trunk body sites (1 – neck, 4 – upper back, 5 – front chest, 6 – lateral chest) for boys and girls of seven age groups. Medians of marked age groups (*) are significantly different for boys and girls by Mann-Whitney U-test (p<0.05).

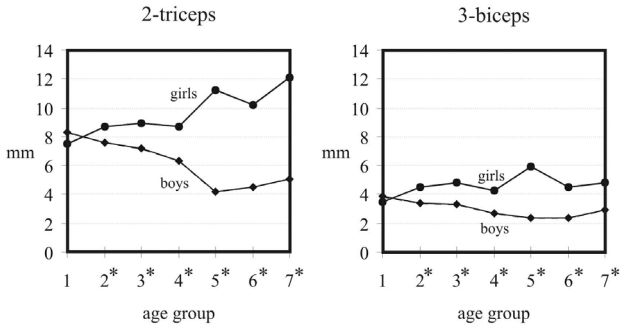


Fig. 3. Medians of body sites of the arm (2 – triceps, 3 – biceps) for boys and girls of seven age groups. Medians of marked age groups (*) are significantly different for boys and girls by Mann-Whitney U-test (p<0.05).

Results

The demographic characteristics of the 1026 children and young adults are presented in Table 1. Table 2 presents the medians of the 15 SAT layers for boys and girls in seven age groups. The medians of boys showed a slight decrease from age group 1 (7–9 yrs) to age group 5 (15–17 yrs) for all SAT layers, which were assigned to four body regions for presentation: the upper trunk (*1 – neck, 4 – upper back, 5 – front chest, 6 – lateral chest*) (Figure 2), the arms (*2 – triceps, 3 – biceps*) (Figure 3), the lower trunk (*7 – upper abdomen, 8 – lower abdomen, 9 – lower back, 10 – hip*) (Figure 4) and the legs (*11 – front thigh, 12 – lateral thigh, 13 – rear thigh, 14 – inner thigh, 15 – calf*) (Figure 5). Between age group 4 (13–15 yrs) and 5 (15–17 yrs) we observed significant decreases (by Mann-Whitney U-test, $p<0.05$, underlined values in Table 2) in all SAT layer thicknesses. Age group 5 (15–17 yrs) was the minimum for all values. Afterwards we found slightly increasing results for age group 6 (17–19 yrs) and 7 (19–21 yrs).

TABLE 2
SAT-Top MEDIANS OF BOYS AND GIRLS IN SEVEN AGE GROUPS. SIGNIFICANT IN-/DECREASES BETWEEN TWO SUBSEQUENT AGE GROUPS ARE UNDERLINED (MANN-WHITNEY U-TEST (P<0.05))

Boys	7–9	9–11	11–13	13–15	15–17	17–19	19–21 Yrs
1 – Neck 1	4.2	3.2	3.1	3.1	2.6	3.0	3.8
2 – Triceps	8.3	7.6	7.2	6.3	4.2	4.5	5.1
3 – Biceps	3.9	3.4	3.3	2.7	2.4	2.4	2.9
4 – Upper back	2.8	2.8	2.7	2.7	2.3	2.6	2.7
5 – Front chest	4.2	3.8	4.0	3.8	3.0	3.0	3.5
6 – Lateral chest	2.3	2.3	2.4	2.5	2.2	2.3	2.9
7 – Upper abdomen	3.2	3.1	3.1	3.2	2.6	2.9	3.9
8 – Lower abdomen	5.0	4.9	4.8	4.8	3.0	3.2	4.0
9 – Lower back	4.9	4.7	4.6	5.1	4.5	4.8	6.0
10 – Hip	4.3	3.8	4.1	3.8	3.5	3.7	4.8
11 – Front thigh	5.8	5.4	5.2	4.1	2.8	3.2	3.1
12 – Lateral thigh	6.4	6.3	6.7	5.5	3.5	3.8	4.0
13 – Rear thigh	4.5	4.7	4.2	3.7	2.8	2.8	3.4
14 – Inner thigh	7.4	7.5	7.2	5.7	3.3	3.4	4.3
15 – Calf	5.0	4.5	4.4	3.5	2.5	2.4	3.0
Girls	7–9	9–11	11–13	13–15	15–17	17–19	19–21 Yrs
1 – Neck 1	3.2	4.1	4.6	5.3	6.2	5.9	6.9
2 – Triceps	7.5	8.7	8.9	8.7	11.2	10.2	12.1
3 – Biceps	3.5	4.5	4.8	4.3	5.9	4.5	4.8
4 – Upper back	2.9	3.5	4.3	3.9	5.3	4.9	5.7
5 – Front chest	3.5	5.5	6.7	5.7	8.6	7.1	7.3
6 – Lateral chest	2.2	2.9	3.8	3.5	5.4	4.5	4.0
7 – Upper abdomen	3.2	4.4	6.9	6.6	10.1	8.1	9.8
8 – Lower abdomen	4.2	6.6	8.6	7.9	8.8	7.4	8.8
9 – Lower back	4.5	6.7	7.6	7.9	9.9	8.2	9.4
10 – Hip	3.8	5.7	6.3	6.7	9.0	6.6	7.9
11 – Front thigh	5.9	7.0	6.7	7.3	7.8	8.8	10.3
12 – Lateral thigh	6.6	7.4	7.7	8.0	8.4	9.4	9.6
13 – Rear thigh	4.1	5.1	5.0	5.4	5.4	6.1	5.9
14 – Inner thigh	7.4	7.6	8.4	8.6	9.6	10.4	10.8
15 – Calf	3.9	4.0	4.5	4.6	4.5	5.3	5.7

[1] SAT thickness of 15 body sites in mm

Girls, on the contrary, showed increasing medians for all SAT layers of the upper trunk (Figure 2), the arms (Figure 3) and the lower trunk (Figure 4), whereby the values in age group 5 (15–17 yrs) culminated in a slight maximum. We found most of the significant increases between age group 4 (13–15 yrs) and 5 (15–17 yrs). All SAT layers of the legs slightly increased through all age groups (Figure 5). Though there were no significant differences between two subsequent age groups (except for one exception), the whole increase through all age groups was significant for all SAT layers of the legs (Kruskal-Wallis H-test for independent samples, $p<0.05$).

The significance of differences between SAT-Top of boys and girls for all age groups is presented in Figures 2-5. There were no significant SAT-Top differences by sex in age group 1 (7–9 yrs). In age group 2 (9–11 yrs), two body sites of the upper trunk and the body sites of the arms deviated significantly between boys and girls. All subsequent age groups provided significantly different results for (almost) the whole SAT-Top.

Figure 6 contains the condensed information on SAT-Top development in children and young adults:

(a) The SAT layer profiles (medians) for boys and girls in age group 1 (7–9 yrs) show a similar »starting pattern« for both sexes.

(b,c) Development of SAT layer profiles through the age groups shows a similar profile for the first age group, followed by decreasing profiles in boys and increasing profiles in girls.

Finally, the discriminating power between male and female SAT-Top was investigated by stepwise discriminant analysis, which provided no significant results for

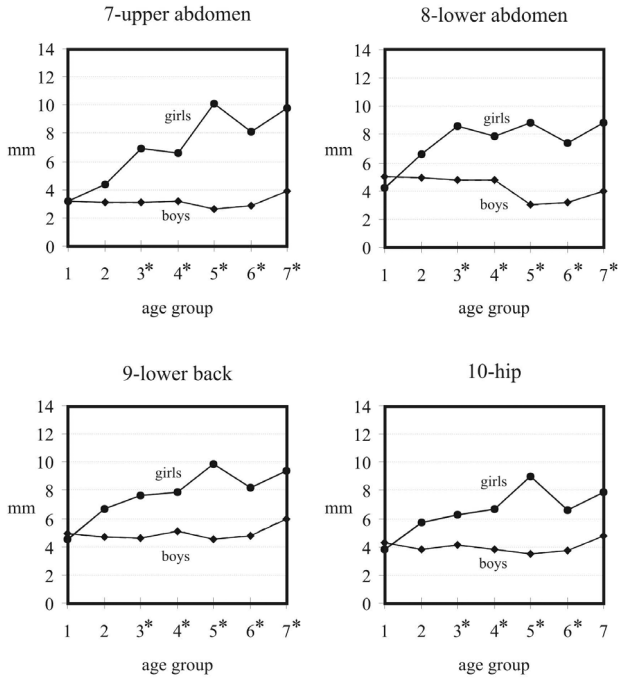
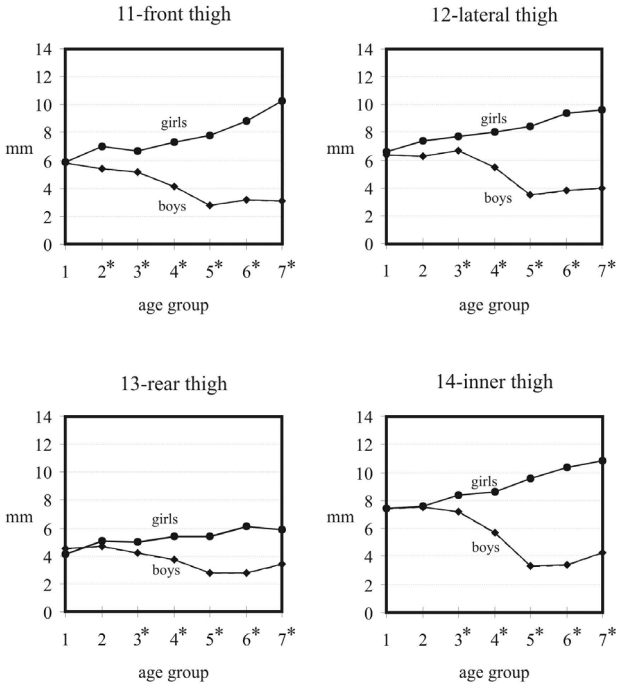


Fig. 4. Medians of lower trunk body sites (7 – upper abdomen, 8 – lower abdomen, 9 – lower back, 10 – hip) for boys and girls of seven age groups. Medians of marked age groups (*) are significantly different for boys and girls by Mann-Whitney U-test ($p < 0.05$).



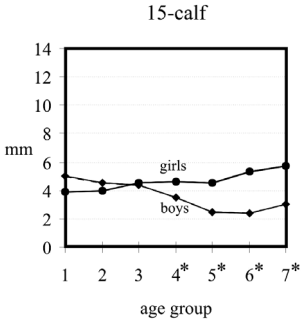


Fig. 5. Medians of body sites of the leg (11 – front thigh, 12 – lateral thigh, 13 – rear thigh, 14 – inner thigh, 15 – calf) for boys and girls of seven age groups. Medians of marked age groups (*) are significantly different for boys and girls by Mann-Whitney U-test ($p<0.05$).

age group 1 (7–9 yrs), about 73% correct classification for age group 2 (9–11 yrs) and 3 (11–13 yrs), 83% for age group 4 (13–15 yrs), and about 91–93% for the following age groups (15–21 yrs) of young adults (Table 3).

Discussion

Hammond[18] has previously presented CALIPER skinfold norm values of British boys (about 3000) and girls (about 560), taking measurements at six body sites: triceps, biceps, sub-scapular (can be compared to *4 – upper back*), supra-iliac (≅ *10 – hip*), sub-costal (≅ *6 – lateral chest*) and abdominal (≅ *8 – lower abdomen*). Compared to our results, triceps, biceps and supra-iliac skinfolds show very similar trends, although CALIPER skinfolds are about 1 mm thicker than LIPOMETER measurements. Sub-scapular, sub-costal and abdominal skinfold means are 1–2 mm higher in the first four age groups (7–15 yrs), and afterwards, in age group 5 (15–17 yrs) and 6 (17–19 yrs), we also find increasing measurement values, which are about 3 mm higher than LIPOMETER results.

In girls the trends of increasing SAT layer thicknesses through all age groups are confirmed by the CALIPER skinfold norm values of six body sites presented by Hammond[18], who reported about 1.5 mm thicker skinfolds at the body sites triceps, biceps and subra-iliac, 2.5 mm greater sub-costal values, and about 3.8 mm higher sub-scapular and abdomen skinfold thicknesses, compared to LIPOMETER medians.

Other median curves of CALIPER skinfold thicknesses measured in British children at the body site triceps[19–20] also provide similar curve shapes (Figure 2) in boys and girls compared to LIPOMETER SAT thicknesses, although LIPOMETER results are about 1–4 mm lower.

Comparing our LIPOMETER results to previously presented norm values for CALIPER skinfolds at comparable body sites, we always find higher values for CALIPER measurements (1–4 mm), whereby great differences (4 mm) are found especially at plain body sites (e.g. sub-scapular), and small differences at rounded body sites (e.g. triceps). Maybe CALIPER skinfolds at plain body sites produce a greater positive measurement error. Generally, the differences between the two methods might be caused by measuring a double layer of skin and

TABLE 3
RESULTS (CORRECT CLASSIFICATION (IN %) AND SIGNIFICANTLY SELECTED BODY SITES) OF STEPWISE DISCRIMINANT ANALYSIS IN DISCRIMINATING BETWEEN SAT-Top OF BOYS AND GIRLS

Age group	7–9	9–11	11–13	13–15	15–17	17–19	19–21 Yrs	
Correct classification								
All subjects	0.0	73.9	73.2	83.1	92.4	93.3	91.3	%
Boys	0.0	81.1	78.1	84.2	95.3	93.9	92.0	%
Girls	0.0	64.1	66.7	81.6	89.3	92.1	90.5	%
Selected body site								
1 – Neck		*		*		*		
2 – Triceps				*	*			
3 – Biceps								
4 – Upper back					*			
5 – Front chest				*				
6 – Lateral chest				*	*	*		
7 – Upper abdomen			*					
8 – Lower abdomen		*						
9 – Lower back				*				
10 – Hip			*	*			*	
11 – Front thigh		*	*	*	*		*	
12 – Lateral thigh			*		*	*		
13 – Rear thigh						*		
14 – Inner thigh								
15 – Calf		*	*	*				

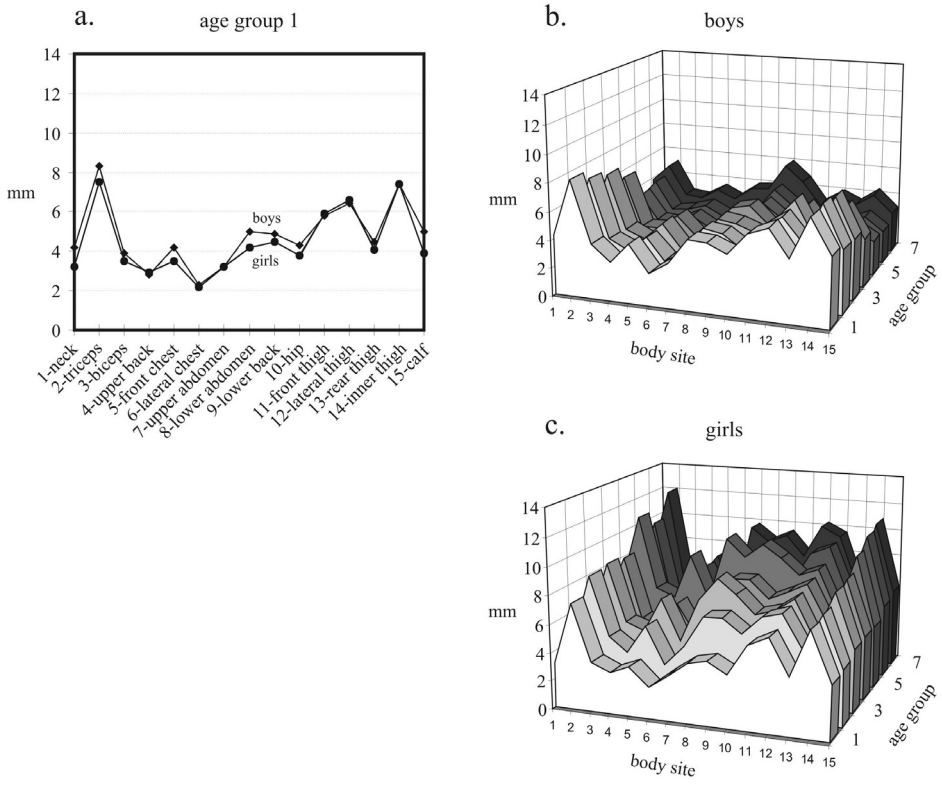


Fig. 6. (a) Male and female SAT-Top (medians) of age group 1 (7–9 yrs). (b) Male SAT-Top (medians) of seven subsequent age groups. (c) Female SAT-Top (medians) of seven subsequent age groups.

a compressed double layer of SAT using the CALIPER technique, which leads to inaccurate measurements[21]. However, comparing data collected with LIPOMETER and CALIPER can only be valid if the measurements were performed on the same individuals. Otherwise the differences between the measurement devices could be due to other factors.

There is a well-known »masculinizing process« in the SAT development of adults, which redistributes the body fat away from the extremities towards the trunk[6,14,22]. A consistent increase in regional adiposity and body composition with age, among 10–16 year old urban Bengalee boys, and an increase in mean WHR at 16 years of age has been demonstrated lately[13].

Reflecting the human SAT-Top development we find no significant differences between 7–9 year-old boys and girls in the first age group. Afterwards, boys immediately start to reduce fat at the extremities (masculinizing process). Up to age group 5 (15–17 yrs) their trunk body fat also decreases, but afterwards it starts to increase again, which means that the complete masculinizing process has begun. Trunk body fat in women increases from the age of 7 to 70 (masculinizing process)[6], but during all subsequent age groups of children and young adults thicker SAT layers are found at the extremities (especially at the legs), which develops the special female fat pattern. Afterwards, from 20 to 70 yrs, extremity fat decreases in women, which completes the masculinizing process[6]. In conclusion, our results show that boys start to develop this masculinizing process earlier.

Our data show the exact beginning of the masculinizing process in girls and boys, which might contribute to describing a certain risk for developing chronic diseases such as diabetes[23] or atherosclerosis later in life.

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E. Tafeit

Institute of Physiological Chemistry, Center of Physiological Medicine, Medical University Graz, Harrachgasse 21/II, A-8010 Graz, Austria
e-mail: erwin.tafeit@meduni-graz.at

RAZVOJ SUPKUTANE TOPOGRAFIJE MASNOG TKIVA (SAT-TOP) KOD DJECE I ADOLESCENATA

SAŽETAK

Mjerenja tjelesne građe u svrhu razjašnjenja dinamike srodnih bolesti u pedijatriji dobivaju na važnosti. Metode koje se koriste ne smiju izlagati osobe visokim dozama radijacije te zahtijevaju čvrstu suradnju. Lipometar je novi optički uređaj koji omogućuje neinvazivnu, brzu i sigurnu odluku o debljini slojeva potkožnog masnog tkiva (SAT) na bilo kojem mjestu u ljudskom tijelu. Topografska specifikacija 15 jednako raspoređenih mjesta na tijelu, koja omogućuje precizno mjerenje raspoređenosti potkožne tjelesne masnoće, naziva se supkutana topografija masnog tkiva (SAT-Top). SAT-Top je primijenjen na više od 1000 djece i adolescenata između 7. i 21. godine. U ovom radu opisan je razvoj supkutane topografije masnog tkiva na subjektima različitih dobnih skupina te muške i ženske razlike u svakoj starosnoj skupini. SAT profili slojeva (medijani 15 mjesta u organizmu) za djevojčice i dječake u dobnoj skupini 1 (7–9 godina) pokazuju vrlo sličan uzorak za oba spola, praćen neznatnim smanjenjem debljine SAT slojeva kod dječaka i povećanje vrijednosti kod djevojaka u kasnijim dobnim skupinama. Između dobne skupine 3 (11–13 godina) i dobne skupine 7

(19–21 godina) SAT-Top kod oba se spola značajno razlikuje. Diskriminirajuća snaga SAT-Topa između djevojaka i dječaka dobivena je analizom postupne diskriminacije, koja nije pružila statistički značajne rezultate za dobnu skupinu 1 (7–9 godina), oko 73 % točne klasifikacije za dobnu skupinu 2 (9–11 godina) i 3 (11–13 godina), 83 % za dobnu skupinu 4 (13–15 godina) i 91–93 % za preostale dobne skupine (15–21 godina). Poznato je da je razvoj SAT-a isti u oba spola do puberteta, kada djevojke dobivaju relativno više masnog tkiva od dječaka, kako bi dosegle veći postotak tjelesnih masnoća kao odrasle. Ovaj rad prikazuje precizni opis razvoja SAT-a kod dječaka i djevojaka od djetinjstva do adolescencije, što pruža temelj za buduća istraživanja.