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ORIGINAL ARTICLE

Subtraction of subcutaneous fat to improve the prediction of visceral adiposity: exploring a new anthropometric track in overweight and obese youth

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Background: The efficiency of traditional anthropometric measurements such as body mass index (BMI) or waist circumference (Waist C) used to replace biomedical imaging for assessing visceral adipose tissue (VAT) is still highly controversial in youth.

Hypothesis and Objectives: We evaluated the most accurate model predicting VAT in overweight/obese youth, using various anthropometric measurements and their correlation with different body fat compartments, especially by testing, for the first time in youth, the hypothesis that subtracting the anthropometric measurement the most highly correlated with subcutaneous abdominal adipose tissue (SAAT) and less correlated possible with VAT from an anthropometric abdominal measurement highly correlated with visceral and total abdominal adipose tissue (TAAT), predicts VAT with higher accuracy.

Subjects and Methods: VAT and SAAT data resulted from magnetic resonance imaging (MRI) analysis performed on 181 boys and girls (7-17 y) from *Diabetes & Endocrinology Care Paediatrics Clinic* in Luxembourg. Height, weight, abdominal diameters, waist, hip, and thigh circumferences were measured with a view to developing the anthropometric VAT predictive algorithms.

Results: In girls, subtracting proximal thigh circumference (Proximal Thigh C), the most closely correlated anthropometric measurement with SAAT, from Waist C, the most closely correlated anthropometric measurement with VAT was instrumental in improving VAT prediction, in comparison with the most accurate single VAT anthropometric surrogate.

$$\mathrm{VAT_{Girls}} = 1.111 \times \mathrm{Waist\,C} - 0.675 \times \mathrm{Proximal\,Thigh\,C} + 0.26\,\mathrm{age} - 46.761 \left(R^2 = 55.7\%, P < 10^{-4}\right)$$

Residual analysis showed a negligible estimation error (5 cm^2). In boys, Waist C was the best VAT predictor.

Conclusions: Subtraction of abdominal subcutaneous fat is important to predict VAT in overweight/obese girls.

KEYWORDS

anthropometry, children, MRI, obesity, visceral adipose tissue

1 | INTRODUCTION

Owing to the high implication of visceral adipose tissue (VAT) in an increasing number of cardiometabolic complications such as insulin resistance,[1] hyperlipidaemia, and arterial hypertension from early childhood onwards,[2,3] several studies are still searching for the most accurate and simple method to assess this ectopic fat deposition in youths.[4–13] When it comes to the accurate assessment of VAT in adults, the most privileged investigators have access to the VAT gold-standard-assessment methods, computed tomography (CT-scan), and magnetic resonance imaging (MRI).[14] However, the investigations using these techniques are particularly scarce in youth probably by reason of their large burdens in terms of image-acquisition time, financial cost, and CT-scan irradiation.[4,5] Therefore, indirect anthropometric assessment has been used to estimate VAT. However, the efficiency of these anthropometric tools to replace biomedical imaging is still highly controversial.[4–13] While certain authors advocate Waist C as the strongest predictor for VAT,[5,9] others are in favour of body mass index (BMI) and/or sagittal abdominal diameter (SAD).[7,10]

Moreover, some child studies attempted to combine at least two parameters, such as BMI, and Waist C or BMI Z-score and SAD. Nevertheless, such associations showed poor abilities for VAT prediction.[7,10,11] MRI, rather than anthropometry, is still recommended as the most accurate technique to assess abdominal/visceral fat in children[12] in spite of its previously mentioned burden.

Therefore, if we are to obtain an accurate anthropometric tool predicting VAT from childhood onwards without resorting to the costly method of biomedical imaging, we need an innovative concept.

In our previous study on adults,[1] we showed that whenever we subtract a well correlated anthropometric measurement with subcutaneous abdominal adipose tissue (SAAT) while being the least correlated with VAT (given the fact that VAT had to be kept), from a well correlated anthropometric measurement with total abdominal adipose tissue (TAAT) which is the most correlated possible with VAT (with a view to keeping the maximal amount of VAT), we manage to predict VAT accurately in both men and women. We called this concept "VAT = TAAT − SAAT".[1] Our work was motivated by the fact that the classical anthropometric parameters usually used to predict VAT (such as Waist C or SAD) reflect in reality more TAAT (VAT + SAAT) than VAT (Figure 1). In adults, our findings suggested the subtraction of proximal thigh circumference (Proximal Thigh C) from Waist C.[1]

In this study, we sought to evaluate the most accurate anthropometric model predicting VAT in overweight and obese children, using various anthropometric measurements, the correlation between anthropometric measurements and different body fat compartments, especially by investigating the "VAT = TAAT − SAAT" concept.[1]

2 | METHODS

2.1 | Subjects

Between September 2006 and June 2008, 181 Europid boys (N = 85) and girls (N = 96) from the *Diabetes & Endocrinology Care Paediatrics Clinic* (Luxembourg), overweight or obese according to IOTF definition[15] and aged 7-17 y, participated in the study after giving their informed consent, as well as parental consent. Exclusion criteria included leptin deficiency, hypoparathyroidism, the Prader Willi syndrome, and the Laurence Moon Biedl syndrome because of

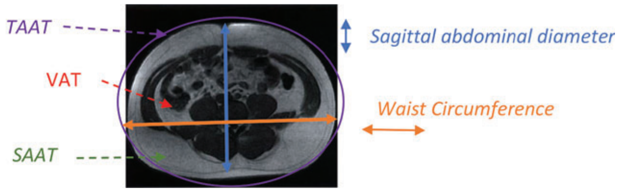

FIGURE 1 Single slice of abdominal fat at the level of L4-L5 using magnetic resonance imaging (MRI).

potential related body-composition alterations. The experimental protocols and the process for obtaining informed consent were approved by the National Ethics Committee of Research (CNER), the National Commission for Data Protection (CNPD) and are in accordance with the Declaration of Helsinki.

2.2 | Measurements

2.2.1 | MRI analysis

To document VAT, all study subjects underwent abdominal MRI. Images were taken in supine position with both arms parallel to their body, on a 1.5-T magnet (GE Signa HDXT System, General Electric Medical Systems, Milwaukee, Wisconsin) using a 8-channel phased-array body coil. During breath holding, a set of eight contiguous images was obtained, centred at vertebral bodies of the L4-L5 level, by using a T1 weighted gradient echo pulse sequence (2D Fast Spoiled Gradient Recalled echo (FSPGR), TR = 120 ms, TE = 4 m, flip angle = 90°, number of excitations = 1, field of view = 48 cm, slice thickness = 10 mm, matrix = 512 × 224, time of acquisition = 13 s). The acquired images were retrieved from the MRI scanner using the DICOM protocol. VAT was rated by a single investigator using a semi-quantitative method developed in IMAGEJ, U.S. National Institutes of Health, Bethesda, Maryland.[16] This approach has been shown to provide good intra and inter-raters reproducibility.[17] In short, the MRI axial section corresponding to the L4-L5 level was loaded into IMAGEJ, and a macro was executed that performed the following steps:

- Automated delineation of total body section using binary conversion and holes filling.
- Definition of total adipose tissue by rater-defined threshold, 3-Manual delineation of adipose tissue sections using adjustable predefined masks, 4-Automated quantification of TAAT, SAAT, and VAT areas. At each step of the process, the rater was allowed to visually inspect and validate the adipose area defined.

2.2.2 | Anthropometric measurements

Height, weight, abdominal, and limb adiposity were assessed by anthropometry by a single trained anthropologist in accordance with Lohman's anthropometric reference manual[1,18]:

- Waist C, performed midway between the lower rib and iliac crest on the midaxillary line;
- abdominal diameters, performed at the same level as Waist C, between the 4th and 5th lumbar vertebrae: (1) the sagittal abdominal diameter with the straight blade calliper (SAD_{SBC}); (2) the sagittal abdominal diameter with the curved blade calliper (SAD_{CBC}); (3) the transversal abdominal diameter (TAD_{SBC}) with the straight blade calliper;
- hip circumference (Hip C) performed at the major trochanter level;
- proximal thigh circumference (Proximal thigh C) performed on the gluteal crease and around the thigh;
- mid-thigh (Mid-thigh C) performed halfway between the inguinal ligament and the proximal patella side;
- distal thigh circumference (Distal thigh C) performed on the femoral epicondyle level;

- calf circumference (Calf C) performed halfway between the knee (patella) and the ankle (lateral malleolus);
- arm circumference (Arm C) performed halfway between the acromion and the olecranon;
- forearm circumference (Forearm C) performed halfway between the olecranon and the pisiform.
- BMI, WHR, and Waist C/height were calculated. Pubertal status was estimated through Tanner stages.[19,20]

2.2.3 | Data analysis

In the absence of national LMS data, Dutch L, M, and S values were used to establish BMI Z Scores.[21] Overweight and obesity thresholds were established by means of the free LMS Growth software developed by Cole.[22] Thresholds were the 91th percentile for overweight and the 99th percentile for obesity in boys, respectively the 89th and 98th percentiles in girls.[21,22]

We defined the most accurate anthropometric model predicting VAT in overweight and obese children according to three processes:

Firstly, we tried to validate the hypothesis "VAT = TAAT − SAAT" through an empirical selection and association of a well correlated anthropometric measurement with TAAT while being the most correlated possible with VAT and the parameter the most correlated possible with SAAT. The latter had to be the less correlated possible with VAT. Univariate analyses were performed to select the variables. Multivariable linear regressions were carried out to build the empirical multivariable anthropometric predictive models of VAT.

Then, we validated the "VAT = TAAT − SAAT" concept with descending and ascending stepwise regressions, carrying out an automatic choice of the VAT predictive variables, which consequently validated the empirical models. All models were age, sex, and pubertal status adjusted.

Finally, Bland and Altman's adapted representations[23] were performed to test the precision of the new anthropometric developed models regarding MRI, which was considered the gold-standard method to assess VAT. Differences between the VAT values predicted by the anthropometric developed models (VAT_{model}) and the VAT values measured by MRI (VAT_{MRI}), or residuals [$VAT_{model} - VAT_{MRI}$], were calculated and regressed on the average of the two methods (Bland and Altman plots).

We used SPSS for Windows, Version 17.0 to perform statistics.

3 | RESULTS

Table 1 details the participants' characteristics.

The most-highly correlated anthropometric measurement with VAT while being well correlated with TAAT was SAD_{CBC} in girls, respectively Waist C in boys.

Proximal thigh C was the most-highly correlated anthropometric variable with SAAT while being the least correlated possible with VAT in both genders (Table 2).

The empirical-based models establishment showed that, after age, BMI, and pubertal status adjustment, the global variance (R^2 Model) explained by the multivariable predictive model of VAT associating SAD_{CBC} with Proximal thigh C in girls was in the order of 60.1% (R Model = 0.776, P Model $<10^{-4}$; $R_{partial}$ SAD_{CBC} = 0.347, $P_{partial}$ SAD_{CBC} $<10^{-4}$; $R_{partial}$ Proximal thigh C = −0.204, $P_{partial}$ proximal thigh C = 0.004; $R_{partial}$ age = 0.278, $P_{partial}$ age $<10^{-4}$. BMI and pubertal status were not significant in the model). In boys, the multivariable linear model associating Waist C with Proximal thigh C, age, pubertal status, and BMI explained 57.1% of the global variance (R^2 Model) but the $P_{partials}$ of Proximal thigh C, age, pubertal status, and BMI were not significant (R Model = 0.756, P Model $<10^{-4}$; $R_{partial}$ Waist C = 0.224, $P_{partial}$ Waist C = .004).

The descending stepwise regression validated the empirical selection of Waist C we made in boys (Table S1, Supporting Information, Model 22: $R_{Pearson}$ = 0.747; R^2 = 0.558; $P < 10^{-4}$), respectively SAD_{CBC} and Proximal thigh C in girls. These latter were significantly associated with weight and age in girls in the descending stepwise procedure (Table S2, Model 19: $R_{Pearson}$ = 0.780; R^2 = 0.609). These results were confirmed by ascending regression, as well.

However, after empirical and automatic models establishment and for reasons of practicality, we made the choice to consider only Waist C in the multivariable model in girls, instead of SAD_{CBC}, even if the global variance of this model was slightly lower (R^2 = 0.557 vs R^2 = 0.609). Actually, Waist C is easier to measure than SAD_{CBC}. This choice was also justified by the fact that Waist C was well correlated with TAAT and VAT in girls, and both parameters assess TAAT as well (Table 2, column 2, third position).

TABLE 1 Subject characteristics[a]

	Girls (N = 96) Mean ± SD Min-Max	Boys (N = 85) Mean ± SD Min-Max
Age (y)	12.4 ± 2.4	11.9 ± 2.3
	7.4-17.3	7.3-17.0
Weight (kg)	70.1 ± 22.1	68.8 ± 19.3
	33.9-151	35.1-117.9
BMI (kg/m^2)	28.6 ± 5.6	28.2 ± 4.7
	19.6-47.4	19.8-41.3
BMI Z score	1.8 ± 0.5	1.8 ± 0.5
	0.5-3.2	0.7-3.0
Waist C (cm)	84 ± 12.1	86.7 ± 11.3
	63-123	68-116
SAD_{CBC} (cm)	21.2 ± 4.1	22.1 ± 3.8
	14-35.5	14.5-33
Proximal thigh C (cm)	61.4 ± 9.1	57.2 ± 8.3
	44-85	18-78
VAT (cm^2)	37.5 ± 18.9	42.5 ± 20.1
	6.24-115.1	11.8-93.2
SAAT (cm^2)	363.2 ± 138.6	336.7 ± 124.3
	110.44-864.9	114.8-739.1
TAAT (cm^2)	400.7 ± 150.0	379.2 ± 136.2
	116.7-911.6	138.9-783.6

[a]Data are presented as mean ± standard deviation and with minimum and maximum range.

Abbreviations: BMI, body mass index; Waist C, waist circumference; SAD_{CBC}, sagittal abdominal diameter with the curved blade calliper; Proximal thigh C, proximal thigh circumference; VAT, visceral adipose tissue; SAAT, subcutaneous abdominal adipose tissue; TAAT, total abdominal adipose tissue.

TABLE 2 Pearson's correlation coefficients (*R*) between VAT, SAAT, TAAT, and anthropometric measurements.

Anthropometric measurement	VAT *R*	TAAT *R*	Anthropometric measurement	SAAT *R*	TAAT *R*
Girls					
SAD_{CBC}	*0.636†*	0.858†	BMI	0.942†	0.944†
SAD_{SBC}	0.623†	0.884†	Waist C	0.919†	0.934†
Waist C	*0.618†*	0.934†	Hip C	0.882†	0.883†
TAD_{SBC}	0.549†	0.874†	SAD_{SBC}	0.866†	0.884†
BMI	0.517†	0.944†	Proximal thigh C	*0.865†*	0.857†
Hip C	0.480†	0.883†	TAD_{SBC}	0.864†	0.874†
Forearm C	0.442†	0.632†	Mid-thigh C	0.857†	0.852†
Mid-thigh C	0.424†	0.852†	Distal thigh C	0.842††	0.834†
Calf C	0.418†	0.764†	SAD_{CBC}	0.837†	0.858†
Proximal thigh C	*0.391†*	0.857†	Calf C	0.763†	0.764†
Distal thigh C	0.381‡	0.834†	Forearm C	0.620†	0.632†
Arm C	0.347‡	0.480†	Arm C	0.469†	0.480†
WHR	0.260‡	0.033	WHR	0.003	0.033
Boys					
Waist C	*0.766†*	0.876†	BMI	0.893†	0.913†
Hip C	0.733†	0.888†	Hip C	0.859†	0.888†
BMI	0.695†	0.913†	Waist C	0.840†	0.876†
SAD_{CBC}	0.688†	0.823†	SAD_{SBC}	0.807†	0.831†
SAD_{SBC}	0.671†	0.831†	SAD_{CBC}	0.795†	0.823†
Arm C	0.662†	0.798†	Distal thigh C	0.783†	0.802†
TAD_{SBC}	0.632†	0.750†	Arm C	0.772†	0.798†
Forearm C	0.627†	0.676†	Mid-thigh C	0.749†	0.765†
Distal thigh C	0.620†	0.802†	TAD_{SBC}	0.723†	0.750†
Mid-thigh C	0.580†	0.765†	Calf C	0.685†	0.704†
Calf C	0.559†	0.704†	Proximal thigh C	*0.674†*	0.694†
Proximal thigh C	*0.556†*	0.694†	Forearm C	0.643†	0.676†
WHR	0.102	0.038	WHR	0.025	0.038

[a]Adjusted to age, BMI, and maturity status.

†*P*-value < .0001; ‡*P*-value < .05.

Abbreviations: Arm C, Arm circumference; BMI, Body Mass Index; Calf C, calf circumference; Distal thigh C, Distal thigh circumference; Forearm C, Forearm circumference; Hip C, Hip circumference; Mid-thigh C, Mid-thigh circumference; Proximal thigh C, Proximal thigh circumference; SAAT, subcutaneous abdominal adipose tissue; SAD_{CBC}, sagittal abdominal diameter with the curved blade calliper; SAD_{SBC}, sagittal abdominal diameter with the straight blade calliper; TAAT, total abdominal adipose tissue; TAD_{SBC}, transversal abdominal diameter with the straight blade calliper; VAT, visceral adipose tissue; Waist C, Waist Circumference; WHR, waist to hip circumference.

Therefore, the following models were considered:

1. In boys: VAT = 0.747 × Waist C − 72.53 ($R_{Pearson}$ = 0.747; R^2 = 0.558);
2. In girls: VAT = 1.11 × Waist C–− 0.675 × Proximal thigh C + 0.26 × Age–− 46.761 ($R_{Pearson}$ = 0.746; R^2 = 0.557).

We removed weight from the multivariable model in girls as it became no significant after replacing SAD_{CBC} by Waist C in girls.

The Bland and Altman adapted representations of these two models (Figures 2a and 2b) provided a graphic illustration of the difference between VAT as measured by MRI and VAT as predicted by the newly developed anthropometric models [VAT_{Model} − VAT_{MRI} (cm^2)] as a function of the average of VAT as assessed by both methods [mean ($VAT_{Model,MRI}$) (cm^2)]. For both genders, the residuals means were significantly different from zero, suggesting a systematic error of VAT prediction by anthropometric models. In girls, a systematic overestimation by the model combining Waist C, Proximal thigh C, and age was shown in case of VAT values lower than 40 cm^2 in particular ($R_{Pearson}$ = −0.799; $P < 10^{-4}$; 5 cm^2 on average; Figure 1A). For VAT values greater than 40 cm^2, the anthropometric model seems to underestimate VAT prediction when compared with MRI in girls. In boys, a systematic negative bias with an overall underestimation of VAT assessment by the anthropometric model was shown ($R_{Pearson}$ = −0.827; $P < 10^{-4}$; 50 cm^2 on average; Figure 1B). Limits of agreement ranged between −24.44 and 34.43 in girls. Wide limits of agreement [residual mean−2 standard deviation/residual mean + 2 standard deviation] were observed in boys: [−80.07/−20.59 cm^2].

4 | DISCUSSION

Anthropometric measurements offer an indirect assessment of VAT, less expensive, and easier to use than MRI and/or CT-Scan, the performances of which have been widely proved.[14] A judicious choice of anthropometric tools based on the objective to be achieved (TAAT,

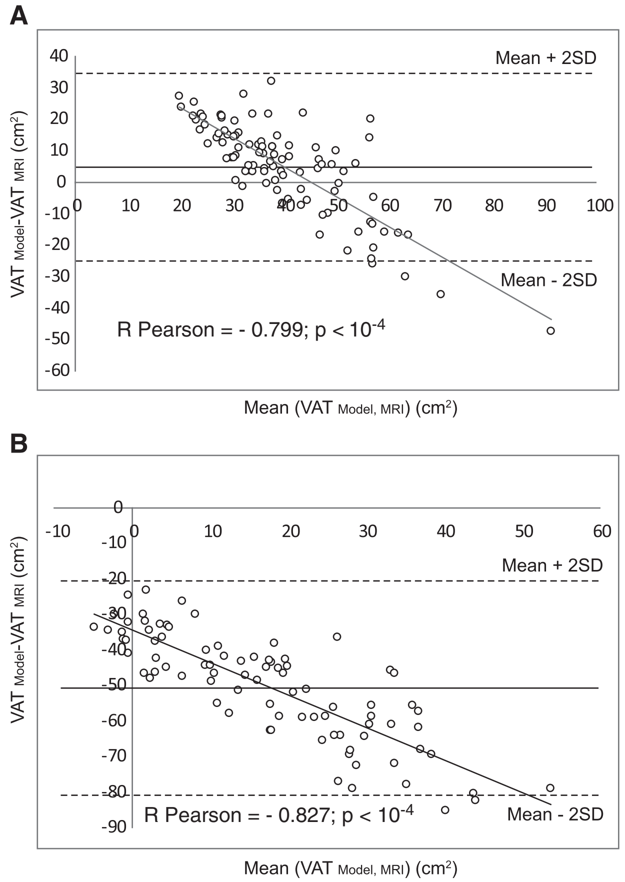

FIGURE 2 Bland and Altman representation of the differences between anthropometric predicted and magnetic resonance imaging (MRI) assessed visceral adipose tissue (VAT) values against means of the predicted and assessed VAT values. (A) In girls. (B) In boys.

VAT, or SAAT assessment) would allow their suitable use in research, by clinicians and/or by non-specialized investigators in body composition. In this study, we evaluated the performances of the innovative anthropometric "VAT = TAAT − SAAT" concept[1] to predict VAT in children, in comparison with MRI, the gold-standard biomedical technology.[14] To our knowledge, no study developing this concept in children has hitherto been published.

Our results showed that VAT prediction model is different from genders: in girls, VAT prediction model using "Waist C" and "Proximal Thigh C" was more closely correlated with VAT as assessed by MRI (R^2 = 55.7%, $P < 10^{-4}$) than using only "Waist C" (R^2 = 38.19%). "Proximal thigh C" was the most reliable indicator of subcutaneous fat and inversely associated with VAT in the multivariable model, which validate our hypothesis: "VAT = TAAT − SAAT" in girls. In boys, VAT seems to be best predicted by Waist C only. These results in girls were in line with our previous findings in women.[1]

According to our previous work in adults, the intra- and inter observer(s) precision of anthropometric measurement of waist and thigh circumferences are in the order of 1 (intra-observer precision for both measurements), 0.93 to 0.99 (inter-observer precision for Proximal Thigh C), respectively 0.99 to 1 (inter-observer precision for Waist C).[1]

On the other hand, the Bland and Altman representation showed that with regard to MRI, Waist C underestimates VAT systematically by 50 cm^2 on average in boys, in an increasing way with VAT degree. Nevertheless, this systematized error of VAT estimation was negligible in girls when using the anthropometric multivariable model combining Waist C and Proximal Thigh C (5 cm^2). These systematized errors of estimation might be partially explained in boys by the fact that Waist C constitutes a composite measurement of abdominal fat, not allowing VAT and SAAT differentiation. In girls, the slight VAT estimation error might be due to the fact that subtracting Thigh C, a SAAT indicator, from Waist C, a TAAT and VAT surrogate, minimizes the bias.

In boys, our findings were in line with several studies highlighting Waist C as the most accurate predictor of VAT. Barreira et al. observed a significant linear relationship between VAT and Waist C.[24] Goodwin et al. found that Waist C accounted for 61% of VAT variance in Caucasian adolescents, BMI accounted for 58% respectively.[11] Benfield et al.[5] performed regression analysis to compare Waist C and BMI abilities in VAT prediction for 12-14-y-old British children. Waist C explained 67.4% and BMI 65.9% of the VAT variance in this study. Brambilla et al. used MRI to assess VAT in 7-16-y-old Caucasian and Hispanic children and developed a predictive equation of VAT. VAT was included as dependent variable and Waist C, BMI, weight, ethnicity, age, pubertal status, and gender as independent variables. The variance explained by Waist C was of the order of 64.8%. BMI, weight, age, and pubertal status did not account for any variance. Ethnicity and gender explained less than 3% of the global model variance.[9] The variances explained by Waist C in the aforementioned studies were, however, somewhat higher than those obtained in our research (55.8% in boys). In our study, moreover, BMI was not a significant predictive measurement of VAT when added to Waist C in boys. In the literature, some authors showed that the associations of Waist C and BMI with VAT do not substantially differ, suggesting that the assessment of Waist C, a more complex measurement than BMI, might be not required.[5–7,9,11]

The fact that our "VAT = TAAT − SAAT" concept was not validated in boys in this study might be imputable to the small size sample. Moreover, Proximal Thigh C was much less closely correlated with SAAT in boys ($R_{Pearson}$ = 0.67) than Waist C ($R_{Pearson}$ = 0.84). Also, Waist C in boys accounts for both VAT (R^2 = 55.8%) and SAAT (R^2 = 70.6%). This is in agreement with several paediatric studies. In the study conducted by Goodwin et al., for example, Waist C accounted for 61% of the VAT variance in boys and 67% of the SAAT variance.[11] Waist C, age, and race were significantly associated with SAAT in 5-18-y-old youths in the study conducted by Barreira et al. Waist C was also significantly correlated with VAT in the same population.[24] Brambilla et al. showed that the variance explained by Waist C was higher for SAAT prediction (80.4%) than for VAT prediction (64.8%).[9] A study by Karlsson et al. showed that Waist C is clearly more correlated to trunk fat mass by DXA ($R_{Pearson}$: 0.86), a composite surrogate for both SAAT and VAT, than to visceral adipose tissue by MRI ($R_{Pearson}$: 0.43).[12]

As in the present research, certain authors attempted to associate several anthropometric measurements in order to predict VAT. Goodwin et al. in particular investigated the implication of the suprailiac skinfold and WHR to predict VAT, in addition to BMI and Waist C. The suprailiac skinfold was closely associated with VAT (variance explained: 62% in boys, 52% in girls).[11] WHR accounted for 22% of the VAT variance in boys, respectively 20% in girls.[11] In the study conducted by Ball et al. Waist C, Tanner stage, and calf skinfold explained the respective following variances in the VAT predictive model: 50%, 4.2%, and 1.7%.[13] Koren et al. performed a hierarchical regression to predict VAT by combining SAD, Waist C, BMI, and BMI Z-score as independent variables. BMI Z-score (R^2 = 34%) and SAD (R^2 = 31%) were the strongest predictors of VAT in obese adolescents.[7] Owens et al. tried to predict VAT by combining 13 anthropometric variables: height, weight, BMI, triceps and calf skinfolds, SAD, Waist C, Hip C, Thigh C, WHR, waist/thigh ratio, SAD/Thigh C ratio and percent body fat from the sum of calf and triceps skinfolds; as well as age, gender, and ethnicity. The final stepwise multiple regression model highlighted SAD, WHR, and ethnicity as significant predictive variables.[10]

The issue lies in the fact that we are not able to quantify VAT with such measures. WHR, for example, is only an anthropometric indicator of the adiposity distribution phenotype. Skinfolds thickness indirectly measures SAAT rather than VAT. Furthermore, these models were based on random anthropometric associations. To our knowledge, no previously published paediatric studies have based the anthropometric prediction of VAT on anatomic and/or physiopathological hypotheses as developed in this research. For this precise reason, we were unable to compare our findings in girls with any other paediatric research.

In conclusion, our findings suggest usefulness of taking into consideration Proximal Thigh C measurement in addition to Waist C in overweight and obese girls. Subtraction of abdominal subcutaneous fat is important to predict VAT in girls.

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REFERENCES

1. Samouda H, Dutour A, Chaumoitre K, Panuel M, Dutour O, Dadoun F. VAT = TAAT-SAAT: innovative anthropometric model to predict visceral adipose tissue without resort to CT-Scan or DXA. *Obesity*. 2013;21:E41–E50.
2. Bosch TA, Dengel DR, Kelly AS, Sinaiko AR, Moran A, Steinberger J. Visceral adipose tissue measured by DXA correlates with measurement by CT and is associated with cardiometabolic risk factors in children. *Pediatr Obes*. 2015;10:172–179.
3. Cohen M, Syme C, Deforest M, et al. Ectopic fat in youth: the contribution of hepatic and pancreatic fat to metabolic disturbances. *Obesity*. 2014;22:1280–1286.
4. Samara A, Ventura EE, Alfadda AA, Goran MI. Use of MRI and CT for fat imaging in children and youth: what have we learned about obesity, fat distribution and metabolic disease risk? *Obes Rev*. 2012;13:723–732.
5. Benfield LL, Fox KR, Peters DM, et al. Magnetic resonance imaging of abdominal adiposity in a large cohort of British children. *Int J Obes (Lond)*. 2008;32:91–99.
6. Bigornia SJ, LaValley MP, Benfield LL, Ness AR, Newby PK. Relationships between direct and indirect measures of central and total adiposity in children: what are we measuring? *Obesity*. 2013;21:2055–2062.
7. Koren D, Marcus CL, Kim C, et al. Anthropometric predictors of visceral adiposity in normal-weight and obese adolescents. *Pediatr Diabetes*. 2013;14:575–584.
8. Katzmarzyk PT, Bouchard C. Where is the beef? Waist circumference is more highly correlated with BMI and total body fat than with abdominal visceral fat in children. *Int J Obes (Lond)*. 2014;38:753–754.
9. Brambilla P, Bedogni G, Moreno LA, et al. Crossvalidation of anthropometry against magnetic resonance imaging for the assessment of visceral and subcutaneous adipose tissue in children. *Int J Obes (Lond)*. 2006;30:23–30.
10. Owens S, Litaker M, Allison J, Riggs S, Ferguson M, Gutin B. Prediction of visceral adipose tissue from simple anthropometric measurements in youths with obesity. *Obes Res*. 1999;7:16–22.
11. Goodwin K, Syme C, Abrahamowicz M, et al. Routine clinical measures of adiposity as predictors of visceral fat in adolescence: a population-based magnetic resonance imaging study. *PLoS One*. 2013;8:e79896.
12. Karlsson AK, Kullberg J, Stokland E, et al. Measurements of total and regional body composition in preschool children: a comparison of MRI, DXA, and anthropometric data. *Obesity*. 2013;21:1018–1024.
13. Ball GD, Huang TT, Cruz ML, Shaibi GQ, Weigensberg MJ, Goran MI. Predicting abdominal adipose tissue in overweight Latino youth. *Int J Pediat Obes*. 2006;1:210–216.
14. Snijder MB, van Dam RM, Visser M, Seidell JC. What aspects of body fat are particularly hazardous and how do we measure them? *Int J Epidemiol*. 2006;35:83–92.
15. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ*. 2000;320:1240–1243.
16. Schneider CA, Rasband WS, Eliceiri KW. NIH Image to ImageJ: 25 years of image analysis. *Nat Methods*. 2012;9:671–675.
17. Bonekamp S, Ghosh P, Crawford S, et al. Quantitative comparison and evaluation of software packages for assessment of abdominal adipose tissue distribution by magnetic resonance imaging. *Int J Obes (Lond)*. 2008;32:100–111.
18. Lohmann TG, Roche AF, Martorell R, eds. Anthropometric standardization reference manual. Champaign, IL: Human Kinetics Books, 1988.
19. Marshall WA, Tanner JM. Variations in pattern of pubertal changes in girls. *Arch Dis Child*. 1969;44:291–303.
20. Marshall WA, Tanner JM. Variations in the pattern of pubertal changes in boys. *Arch Dis Child*. 1970;45:13–23.
21. Fredriks AM, van Buuren S, Wit JM, Verloove-Vanhorick SP. Body index measurements in 1996–7 compared with 1980. *Arch Dis Child*. 2000;82:107–112.
22. Cole TJ. Software for LMS method. http://homepagemaccom/tjcole/FileSharing1html. Accessed April 26, 2016.
23. Bland JM, Altman DG. Measuring agreement in method comparison studies. *Stat Methods Med Res*. 1999;8:135–160.
24. Barreira TV, Broyles ST, Gupta AK, Katzmarzyk PT. Relationship of anthropometric indices to abdominal and total body fat in youth: sex and race differences. *Obesity*. 2014;22:1345–1350.

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