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Anthropometric and body composition parameters in adolescents with the metabolically obese normal-weight phenotype

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Abstract

We aimed to investigate the anthropometric and body composition parameters associated with the metabolically obese normal-weight (MONW) phenotype. This cross-sectional study was conducted with 506 adolescents in Brazil (aged 10–19 y). The MONW phenotype was defined as normal-weight, according to BMI/age, and at least one metabolic alteration. Anthropometric measurements were obtained and the DEXA was used for body composition analysis. Crude and adjusted Poisson regression models with robust variance were used to estimate the associations. The phenotype was positively associated with waist circumference (male: prevalence ratio (PR) = 1·05; 95% CI 1·01, 1·09; female: PR = 1·06; 95% CI 1·02, 1·09), waist:height ratio (male: PR = 1·26; 95% CI 1·07, 1·49; female: PR = 1·29; 95% CI 1·07, 1·56) and android:gynoid fat ratio (male: PR = 1·25; 95% CI 1·03, 1·51; female: PR = 1·39; 95% CI 1·20, 1·62), in both sexes. Furthermore, there was a positive association of phenotype with waist:hip ratio (PR = 1·32; 95% CI 1·06, 1·65) and trunk:arm fat ratio (PR = 1·13; 95% CI 1·02, 1·24) only in males and with trunk:leg fat ratio (PR = 2·84; 95% CI 1·46, 5·53), BAIp (PR = 1·06; 95% CI 1·01, 1·12), fat mass index (PR = 1·24; 95% CI 1·10, 1·41) and regional indices of metabolic load and capacity (PR = 1·29; 95% CI 1·09, 1·53), in females. Anthropometric and body composition parameters indicative of central and total fat are associated with the MONW phenotype.

Key words: Metabolically unhealthy normal weight: Body composition: Anthropometric measures: Skeletal muscle: Adiposity: Adolescent: Cardiometabolic risk

Obesity is a global pandemic[1,2] that is associated with comorbidities such as diabetes, hypertension, dyslipidaemia, CVD and some cancers[3,4]. The BMI is a simple index, which considers weight and height, commonly used to classify obesity, but which is not able to differentiate between lean and fat tissue[5]. In this context, it has been recognised that there are individuals who have a high cardiometabolic risk while maintaining body weight within the normal range by BMI, called metabolically obese normal-weight (MONW)[6].

Different criteria are used for the diagnosis of this phenotype, and the condition is often defined by the presence of one or more metabolic alterations[7,8]. Thus, adults with this phenotype, despite their normal-weight, are described as having an unfavourable lipid and glucose profile, as well as an increased risk of diabetes and CVD[9,10]. Studies with adolescents also show that MONW may have reduced HDL, in addition to elevated leptin, insulin, homoeostasis model assessment – insulin resistance, and high TAG levels[11,12]. Also, MONW individuals may be metabolically affected in a similar way to the BMI's overweight group[11].

The identification of this phenotype in normal-weight adolescents suggests that determinants other than BMI may influence clinical outcomes related to cardiometabolic health. The use of anthropometric measurements and body composition indices, independent of the nutritional status classified by BMI, allow an evaluation of the contribution of lean mass and adiposity in predicting the risk of diseases[13] and, thus, could help in the identification of MONW individuals.

Although the researches did already contribute with knowledge about the MONW phenotype, few studies on this subject have been performed with adolescents[11–16]. Besides, the phenotype can often be underdiagnosed in adolescents, due to normal body weight and young age[17]. From this perspective, early identification of MONW adolescents, as well as related

Abbreviations: ALM, appendicular lean mass; FMI, fat mass index; IMLC, indices of metabolic load and capacity; MONW, metabolically obese normal-weight; PR, prevalence ratio; WHR, waist:hip ratio; WHtR, waist:height ratio.

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anthropometric and body composition parameters, becomes important. Therefore, this study aimed to investigate in a sample of normal weight adolescents the anthropometric and body composition parameters associated with the MONW phenotype.

Materials and methods

This study is part of the 'Comparative study between the three phases of adolescence in relation to excess body fat and cardiovascular risk factors for metabolic syndrome', already detailed in other publications[18,19].

Population, design and sampling

Epidemiological study with a cross-sectional design, population-based, conducted with adolescents between 10 and 19 years old, of both sexes, selected from the rural and urban, public and private school population in the municipality of Viçosa, Minas Gerais (MG), Brazil, between the years 2010 and 2013. The sample size was calculated using the StatCalc of the Epi Info software, version 6.04, from a specific formula for cross-sectional studies, considering a total population of 11 898 adolescents in the city of Viçosa/MG[20], an expected prevalence of 50·0 %[21], acceptable variability of 5 %, and 95 % confidence level, totaling a minimum sample of 372 adolescents. When 20 % was added to this to control for confounding factors, a minimum total of 447 was required. A total of 506 adolescents with an appropriate weight according to BMI/age[22] were evaluated in this study.

The inclusion criteria were no regular use of medications that alter blood glucose, insulinaemia, lipid metabolism, and/or blood pressure levels, no participation in a weight reduction or weight control programme, no regular use of diuretics/laxatives, not pregnant or having ever been pregnant, no neck deformities and no diagnosis of infection, acute inflammation or thyroid disease. According to these criteria, twenty-eight adolescents were excluded from the initial study sample.

All participants and their parents/guardians, in the case of volunteers under the age of 18, signed the Informed Consent Form, under the Declaration of Helsinki. The study was approved by the Ethics Committee on Human Research of the Federal University of Viçosa – Comitê de Ética em Pesquisas com Seres Humanos da Universidade Federal de Viçosa (Of. Ref. No. 0140/2010).

Anthropometry

Weight and height were measured by international standard techniques[23] using electronic digital scales (LC 200PP, Marte®) and portable stadiometer (Alturexata®).

Waist circumference (WC) was obtained at the end of a normal expiration, at the midpoint between the lower margin of the last rib and the iliac crest[23], and used continuously. Hip circumference (HC) was measured in the gluteal region, around the largest horizontal circumference between the waist and the knees[23]. The waist:hip ratio (WHR) was obtained by dividing the waist circumference (cm) by the hip circumference (cm), and the waist:height ratio (WHtR) was obtained by the quotient of the waist circumference (cm) by the height measurement (cm), evaluated continuously.

Neck circumference was measured at the midpoint between the spine and the anterior neck, except when the individual had pronounced thyroid cartilage (Adam's apple). In these cases, the circumference was measured just below the thyroid cartilage[24]. This measure was used on an ongoing basis.

The Paediatric Body Adiposity Index (BAIp), calculated from the measurement of hip circumference and height, was also evaluated continuously, according to the equation: BAIp = ((hip circumference (cm)/(height (m))$^{0·8}$)–38[25].

Body composition assessment

For body composition analysis, the dual energy X-ray absorptiometry (DEXA) equipment (Lunar Prodigy Advance DXA System – analysis version: 13.31, GE Healthcare) was used. The participants were barefoot, wearing light clothing, no metal ornaments and fasting for 12 h. The evaluation was performed with each individual in the supine position, through a series of transverse scans from head to toe, with a whole-body scan duration of approximately 10 min. The body composition analysis included android fat, gynoid fat, total fat mass and trunk, arms, and legs fat. Arm and leg fat was defined, respectively, as the sum of the fat in two arms and two legs, both divided by two[26]. The following indices were calculated according to the fat distribution: android: gynoid ratio; trunk:legs ratio; trunk:arms ratio[26,27].

Besides, the fat mass index (FMI) and the fat-free mass index, proposed by Van Itallie et al. (1990)[28], to have a more careful anthropometric evaluation, according to the body compartments, by calculation that considers the amount in kilograms of fat mass and fat-free mass relative to height, as follows: FMI = (body fat (kg)/height (m)^2) and fat-free mass index = ((Weight (kg) – body fat (kg))/height (m)^2).

The body composition analysis also included the lean mass of the legs and arms, and the following parameters were analysed: appendicular lean mass (ALM), obtained by adding the lean mass of the arms and legs. With the ALM data, the lean mass index relative to height (ALM/height^2, given in kg/m^2)[29]; the lean mass index relative to weight (ALM/weight × 100, given in %)[30]; the lean mass index relative to BMI (lean mass index relative to height BMI: ALM/IMC, given in kg/kg/m^2)[31] and the indices of metabolic load and capacity (IMLC), which relate total fat mass to total fat-free mass (TFFM) (total IMLC = total fat mass/TFFM)[32], and trunk fat mass to ALM (regional IMLC = trunk fat mass/ALM) were obtained[32].

Biochemical assessment

Blood samples (12 ml) were collected at the Clinical Analysis Laboratory of the Health Division of the Federal University of Viçosa, after a 12-hour fast, by venipuncture, with disposable syringes. The analyses were carried out at the Nutritional Biochemistry Laboratory of the Department of Nutrition and Health and at the Molecular Immunovirology Laboratory of the Department of General Biology, at the Federal University of Viçosa.

HDL, LDL and TAG analyses were performed on blood serum after the material had been centrifuged in an Excelsa 206 BL centrifuge for 10 min at 3500 rpm. HDL and TAG were measured by the colorimetric enzymatic method, with automation by the

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Cobas Mira Plus equipment (Roche Corp.), and LDL was calculated by Friedewald's formula for TAG values lower than 400 mg/dl[33]. Classification of the lipid profile was performed according to the Integrated Guide for cardiovascular health and risk reduction in children and adolescents (Guia integrado para saúde cardiovascular e redução de risco em crianças e adolescentes)[34], in which altered values (mg/dl) for LDL ≥ 130; HDL < 40 and TAG ≥ 130 are considered.

Fasting blood glucose was measured by the enzymatic glucose-oxidase method using the Cobas Mira Plus (Roche Corp.) automation equipment, and it was considered an altered fasting blood glucose ≥ 100 mg/dl[35]. Fasting insulin was measured by the electrochemiluminescence method. Insulin resistance was calculated through the mathematical model homoeostasis model assessment – insulin resistance, using insulin and fasting blood glucose levels. Homoeostasis model assessment – insulin resistance values ≥ 3·16 were considered as insulin resistance[36].

Blood pressure assessment

Blood pressure was measured, according to the protocol established by the VI Brazilian Guidelines on Hypertension (I Diretriz Brasileira de Hipertensão Arterial)[37], using an automatic inflation blood pressure monitor (Omron® Model HEM-741 CINT), recommended by the Brazilian Society of Cardiology (Sociedade Brasileira de Cardiologia). The blood pressure was measured in the right and left arms, and the measurement was repeated twice in the arm with the highest pressure value, with a 1-minute interval between them, and the average of the last two measurements was taken.

Elevated blood pressure levels were defined as systolic or diastolic blood pressure ≥ percentile 90 by age, sex and height for the adolescents under 13 years of age and for the group aged 13 years and older, systolic blood pressure ≥ 120 mmHg or diastolic blood pressure ≥ 80 mmHg were considered elevated pressure levels, according to the recommendations of the *American Academy of Pediatrics* (2017)[38].

Definition of the metabolically obese normal-weight phenotype

Adolescents who have adequate weight but the presence of at least one metabolic alteration[8] were considered MONW in this study. To evaluate the nutritional status of adolescents and classify them as normal-weight, the BMI was used, obtained by dividing the weight by the square of the height, with values between the percentiles ≥ 3 and < 85, analysed according to sex and age, according to the WHO[22].

Also, it was considered metabolic alterations: high blood pressure[38], high fasting glucose[35], alteration in the lipid profile (low HDL, high LDL or TAG)[34], and insulin resistance by homoeostasis model assessment – insulin resistance[36]. Alteration in at least one of these components defined the metabolic abnormality.

Covariates

A questionnaire was applied to evaluate the profile of the adolescents, such as age, sex and type of school where they study (public or private). Besides, the socio-economic condition was investigated through the application of a questionnaire that collects a variety of social and economic issues at the household level, using the same methodology adopted by the Survey on Living Standards (Pesquisa sobre Padrões de Vida – PPV)[39], which was classified as 'adequate' or 'precarious and intermediate'.

The level of physical activity was assessed using the International Physical Activity Questionnaire – short version, validated for this population group[40] as a way to classify adolescents as sedentary, irregularly active, active and very active[41]. Considering the low prevalence of sedentarism in the studied population, we chose to group the sedentary and irregularly active individuals into insufficiently active, and those considered active and very active were grouped into physically active.

The dietary analysis was performed by applying the qualitative FFQ to know the frequency of consumption of food groups. The FFQ was applied individually, and the adolescents were instructed to report on the frequency of consumption in the month before the date of application of the questionnaire[42].

The list of foods that made up the FFQ was determined considering the foods that are part of the eating habits of adolescents in the city of Viçosa, MG, based on data from the application of 24-h recall tests on adolescents assisted by the Adolescent Health Care Program (Programa de Atenção à Saúde do Adolescente – PROASA) of UFV. Weekly consumption frequency was categorised as ≥ 4 or < 4 times a week[43]. The consumption of fruits, vegetables and legumes was used as a marker of a healthy diet.

Statistical analysis

The database was prepared by a double entry in Microsoft Office Excel 2007. The statistical analyses were performed in STATA software, version 14. The consistency and distribution of the quantitative variables were evaluated by histograms, coefficient of asymmetry and kurtosis and the Shapiro–Wilk normality test. Categorical variables were expressed as absolute and relative frequency; quantitative variables were expressed as mean and standard deviation or median and interquartile range. The statistical differences of the quantitative variables according to the presence or absence of the MONW phenotype were analysed by Student's t test or the nonparametric Mann–Whitney test, according to the normality of the variables, as well as the homogeneity of variances. Statistical differences for categorical variables were calculated by the χ^2 test; or Fisher's exact test for when more than 20 % of the cells had expected counts < 5. In the bivariate analysis, P values < 0·20 were considered for inclusion in the regression models. The WHtR, WHR, android:gynoid ratio and regional IMLC were converted to Z-score in the regression models using the following equation:

Z-score = (individual anthropometric value - mean anthropometric value)/standard deviation[44].

To evaluate the associations of anthropometric and body composition parameters (explanatory variables) with the MONW phenotype (outcome variable), Poisson regression with robust variance was employed, and prevalence ratios (PR) with 95 % CI were estimated. Two independent models were built for each explanatory variable, one crude and one adjusted for potential confounding factors defined according to the literature[6–17] (age, sex, physical activity

level, socio-economic condition, and fruit, vegetable and legume consumption). Regression analysis was used in the total sample, and there was also stratification by sex and age (10–13 years old, 14–16 years old and 17–19 years old). The significance level adopted in all analyses was 5 %.

Results

Among the evaluated adolescents, the majority of participants are female (54·5 %), and the prevalence of the MONW phenotype was 29·1 % (*n* 147) (95 % CI 24·9, 32·9). There were no statistically significant differences in age, sex, school type, socio-economic condition, physical activity level and food intake between the groups with and without the MONW phenotype (Table 1). Regarding the indicative measures of central and total adiposity and the body composition indices, the MONW adolescents presented, compared with the normal-weight adolescents without the phenotype, higher waist circumference (cm), WHtR, WHR, neck circumference (cm), android:gynoid fat ratio, trunk:leg and trunk:arm fat mass ratio and regional IMLC (Table 2).

As for the main metabolic alterations in the MONW group, it was observed that the frequency of participants with altered HDL among those with the MONW phenotype is 46·9 %; also, 23·8 % of MONW adolescents have altered LDL (Fig. 1).

In the adjusted regression models, the MONW phenotype was positively associated with waist circumference (cm) (PR = 1·05; 95 % CI 1·03, 1·08), WHtR (PR = 1·23; 95 % CI 1·07, 1·41), WHR (PR = 1·25; 95 % CI 1·07, 1·47), android:gynoid fat ratio (PR = 1·34; 95 % CI 1·19, 1·51), trunk:leg fat ratio (PR = 2·67; 95 % CI 1·64, 4·32), trunk:arm fat ratio (PR = 1·12;

Table 1. Characterisation of adolescents according to the absence or presence of the metabolically obese normal-weight phenotype (MONW) (Numbers and percentages)

	Total sample (*n* 506)		no MONW (*n* 359)		MONW (*n* 147)		
Explanatory variables	*n*	%	*n*	%	*n*	%	*P* value
Socio-demographic							
Sex							
Female	276	54·5 %	197	54·9 %	79	53·7 %	0·816*
Male	230	45·5 %	162	45·1 %	68	46·3 %	
Age (years)	14·50	3·02	14·46	3·01	14·59	3·08	0·659†
Socio-economic condition							
Adequate	273	54·0 %	192	53·5 %	81	55·1 %	0·740*
Precarious and Intermediate	233	46·0 %	167	46·5 %	66	44·9 %	
Type of school							
Public	444	87·7 %	318	88·6 %	126	85·7 %	0·372*
Private	62	12·3 %	41	11·4 %	21	14·3 %	
Level of physical activity							
Insufficiently active	134	26·5 %	96	26·7 %	38	25·9 %	0·837*
Physically active	372	73·5 %	263	73·3 %	109	74·1 %	
Food consumption							
Milk and dairy products							
Does not consume ≥ 4×/week	120	23·7 %	81	22·6 %	39	26·5 %	0·341*
Consumes ≥ 4×/week	386	76·3 %	278	77·4 %	108	73·5 %	
Meat, sausages and eggs							
Does not consume ≥ 4×/week	78	15·4 %	53	14·8 %	25	17·0 %	0·526*
Consumes ≥ 4×/week	428	84·6 %	306	85·2 %	122	83·0 %	
Fruits							
Does not consume ≥ 4×/week	192	37·9 %	143	39·8 %	49	33·3 %	0·171*
Consumes ≥ 4×/week	314	62·1 %	216	60·2 %	98	66·7 %	
Vegetables							
Does not consume ≥ 4×/week	155	30·6 %	113	31·5 %	42	28·6 %	0·520*
Consumes ≥ 4×/week	351	69·4 %	246	68·5 %	105	71·4 %	
Legumes							
Does not consume ≥ 4×/week	52	10·3 %	35	9·7 %	17	11·6 %	0·542*
Consumes ≥ 4×/week	454	89·7 %	324	90·3 %	130	88·4 %	
Sugar and sweets							
Does not consume ≥ 4×/week	12	2·4 %	9	2·5 %	3	2·0 %	0·999‡
Consumes ≥ 4×/week	494	97·6 %	350	97·5 %	144	98·0 %	
Oils and fats							
Does not consume ≥4×/week	62	12·3 %	45	12·5 %	17	11·6 %	0·763*
Consumes ≥ 4×/week	444	87·7 %	314	87·5 %	130	88·4 %	
Industrialised condiments							
Does not consume ≥ 4×/week	271	53·6 %	190	52·9 %	81	55·1 %	0·656*
Consumes ≥ 4×/week	235	46·4 %	169	47·1 %	66	44·9 %	

The results were expressed as absolute and (relative) frequency for categorical variables. The quantitative variable (age) was expressed as mean and (standard deviation).
* Pearson's χ^2.
† Student's *t* test.
‡ Fisher's Exact Test.

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Table 2. Anthropometric and body composition parameters, according to the absence or presence of the metabolically obese normal-weight phenotype (MONW)

	Total sample (*n* 506)		no MONW (*n* 359)		MONW (*n* 147)		
Explanatory variables	mean / median	SD / interquartile range	mean / median	SD / interquartile range	mean / median	SD / interquartile range	*P* value
Anthropometric and body composition							
Waist circumference (cm)	68·00	10	68·00	10	70·00	10	0·002*
Waist:height ratio	0·44	0·03	0·43	0·03	0·44	0·04	0·008†
Waist:hip ratio	0·84	0·05	0·84	0·05	0·85	0·05	0·027†
Neck circumference (cm)	29·70	3·00	29·5	2·95	30·5	3·40	0·009*
Android/gynoid	0·16	0·07	0·16	0·07	0·18	0·08	< 0·001*
Lean mass (%)	73·34	11·20	75·56	10·74	75·56	8·87	0·993†
Fat mass (%)	19·99	8·14	19·74	7·93	20·59	8·605	0·287†
Trunk FM/Leg FM	0·98	0·34	0·97	0·32	1·02	0·44	0·004*
Trunk FM/Arm FM	7·02	2·40	6·98	2·29	7·36	2·63	0·035*
BAIp	18·96	4·55	18·79	4·61	19·38	4·40	0·183†
FMI (kg/m²)	3·80	1·82	3·72	1·77	4·01	1·92	0·104†
FFMI (kg/m²)	14·90	1·97	14·81	1·90	15·115	2·11	0·110†
LMI height	2·50	1·19	2·46	1·17	2·59	1·23	0·263†
LMI weight	13·12	5·35	13·04	5·25	13·30	5·59	0·617†
LMI BMI	0·33	0·14	0·32	0·14	0·33	0·15	0·381†
Total IMLC	0·26	0·13	0·26	0·13	0·27	0·14	0·212†
Regional IMLC	0·43	0·14	0·42	0·14	0·45	0·18	0·003*

FM, fat mass; BAIp, paediatric body adiposity index; FMI, fat mass index, FFMI, fat-free mass index; LMI height, lean mass index relative to height; LMI weight, lean mass index relative to body weight; LMI BMI, lean mass index relative to body mass index; IMLC, index of metabolic load and capacity.
The results were expressed as mean and (standard deviation) when analysed by Student's *t* test or as median and (interquartile range) when analysed by Mann–Whitney test.
* Mann–Whitney.
† Student's *t* test.

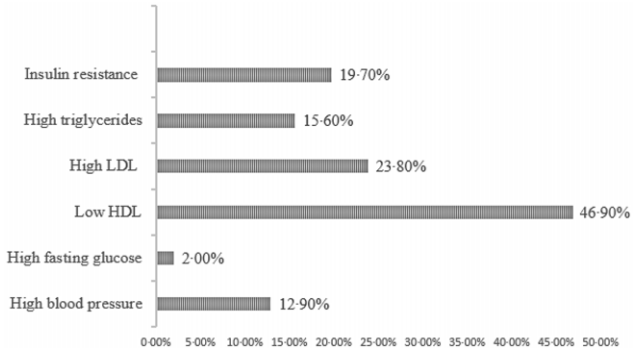

Fig. 1. Distribution of metabolic alterations in adolescents with the metabolically obese normal-weight phenotype.

95 % CI 1·04, 1·21), regional IMLC (PR = 1·32; 95 % CI 1·15, 1·51), as well as with FMI (PR = 1·10; 95 % CI 1·02, 1·22) (Table 3).

In the analysis stratified by sex, there was a positive association between waist circumference (cm) (PR = 1·05; 95 % CI 1·01, 1·09), WHtR (PR = 1·26; 95 % CI 1·07, 1·49), WHR (PR = 1·32; 95 % CI 1·06, 1·65), android:gynoid fat ratio (PR = 1·25; 95 % CI 1·03, 1·51), trunk:arm fat ratio (PR = 1·13; 95 % CI 1·02, 1·24) and the MONW phenotype in males (Table 4). In females, the phenotype was positively associated with waist circumference (cm) (PR = 1·06; 95 % CI 1·02, 1·09), WHtR (PR = 1·29; 95 % CI 1·07, 1·56), android:gynoid fat ratio (PR = 1·39; 95 % CI 1·20, 1·62), trunk:leg fat ratio (PR = 2·84; 95 % CI 1·46, 5·53), BAIp (PR = 1·06; 95 % CI 1·01, 1·12), FMI (PR = 1·24; 95% CI 1·10, 1·41) and regional IMLC (PR = 1·29; 95 % CI 1·09, 1·53) (Table 5).

Furthermore, to check whether the associations differ by age, we analysed them according to the stages of adolescence

Table 3. Association between anthropometric and body composition parameters with the MONW phenotype in adolescents (Prevalence ratios and 95 % confidence intervals, *n* 506)

	Poisson regression with robust variance			
	Crude model		Adjusted model†	
Measures	PR	95 % CI	PR	95 % CI
Waist circumference (cm)	1·03	1·01, 1·05*	1·05	1·03, 1·08*
Waist:height ratio‡	1·19	1·05, 1·36*	1·23	1·07, 1·41*
Waist:hip ratio‡	1·17	1·02, 1·34*	1·25	1·07, 1·47*
Neck circumference (cm)	1·08	1·02, 1·13*	1·09	1·00, 1·19
Android/gynoid‡	1·32	1·18, 1·47*	1·34	1·19, 1·51*
Trunk FM/Leg FM	2·17	1·44, 3·28*	2·67	1·64, 4·32*
Trunk FM/Arm FM	1·10	1·03, 1·18*	1·12	1·04, 1·21*
BAIp	1·02	0·99, 1·05	1·04	1·00, 1·09
FMI (kg/m²)	1·06	0·99, 1·14	1·10	1·02, 1·22*
FFMI (kg/m²)	1·06	0·99, 1·13	1·10	1·00, 1·22
Regional IMLC‡	1·24	1·11, 1·39*	1·32	1·15, 1·51*

FM, fat mass; PR, prevalence ratio; BAIp, paediatric body adiposity index; FMI, fat mass index; FFMI, fat-free mass index; IMLC, index of metabolic load and capacity.
* Statistical significance.
† Adjustment for sex; age; physical activity level; socio-economic condition and consumption of fruits, vegetables,and legumes (healthy diet).
‡ Waist:height ratio, waist:hip ratio, android:gynoid ratio and regional IMLC were converted to Z-score.

(Table 6). In early adolescence (ages 10–13), the phenotype was positively associated with android:gynoid fat ratio (PR = 1·30; 95 % CI 1·10, 1·54), trunk:leg fat ratio (PR = 3·26; 95 % CI 1·47, 7·23), trunk:arm fat ratio (PR = 1·14; 95 % CI 1·02, 1·28) and regional IMLC (PR = 1·31; 95 % CI 1·10, 1·57). In middle adolescence (ages 14–16), there was a positive association with waist circumference (cm) (PR = 1·06; 95 % CI 1·01, 1·12), neck circumference (cm) (PR = 1·25; 95 % CI 1·01,

Table 4. Association between anthropometric and body composition parameters with the MONW phenotype in male adolescents (Prevalence ratios and 95 % confidence intervals, *n* 230)

	Poisson regression with robust variance			
	Crude model		Adjusted model†	
Measures	PR	95 % CI	PR	95 % CI
Waist circumference (cm)	1·04	1·01, 1·07*	1·05	1·01, 1·09*
Waist:height ratio‡	1·26	1·06, 1·50*	1·26	1·07, 1·49*
Waist:hip ratio‡	1·16	0·94, 1·42	1·32	1·06, 1·65*
Neck circumference (cm)	1·09	1·02, 1·17*	1·06	0·93, 1·20
Android/gynoid‡	1·29	1·09, 1·53*	1·25	1·03, 1·51*
Trunk FM/Leg FM	2·29	1·30, 4·03*	1·99	0·95, 4·19
Trunk FM/Arm FM	1·14	1·05, 1·25*	1·13	1·02, 1·24*
BAIp	1·06	1·00, 1·13	1·05	0·97, 1·12
FMI (kg/m²)	1·12	0·96, 1·29	1·13	0·98, 1·29
FFMI (kg/m²)	1·10	1·01, 1·19*	1·05-	0·90, 1·23
Regional IMLC‡	1·29	1·09, 1·52*	1·24	0·99, 1·54

FM, fat mass; PR, prevalence ratio; BAIp, paediatric body adiposity index; FMI, fat mass index; FFMI, fat-free mass index; IMLC, index of metabolic load and capacity.
* Statistical significance.
† Adjustment for age; physical activity level; socio-economic condition and consumption of fruits, vegetables and legumes (healthy diet).
‡ Waist:height ratio, waist:hip ratio, android:gynoid ratio and regional IMLC were converted to *Z*-score.

Table 5. Association between anthropometric and body composition parameters with the MONW phenotype in female adolescents (Prevalence ratios and 95 % confidence intervals, *n* 276)

	Poisson regression with robust variance			
	Crude model		Adjusted model†	
Measures	PR	95 % CI	PR	95 % CI
Waist circumference (cm)	1·02	1·00, 1·05	1·06	1·02, 1·09*
Waist:height ratio‡	1·17	0·98, 1·38	1·29	1·07, 1·56*
Waist: hip ratio‡	1·18	0·99, 1·40	1·19	0·97, 1·47
Neck circumference (cm)	1·09	0·98, 1·21	1·10	0·95, 1·26
Android/gynoid‡	1·33	1·15, 1·55*	1·39	1·20, 1·62*
Trunk FM/Leg FM	2·15	1·11, 4·14*	2·84	1·46, 5·53*
Trunk FM/Arm FM	1·07	0·94, 1·22	1·09	0·96, 1·23
BAIp	1·01	0·97, 1·05	1·06	1·01, 1·12*
FMI (kg/m²)	1·10	0·99, 1·23	1·24	1·10, 1·41*
FFMI (kg/m²)	0·99	0·84, 1·15	1·05	0·87, 1·26
Regional IMLC‡	1·21	1·03, 1·43*	1·29	1·09, 1·53*

FM, fat mass; PR, prevalence ratio; BAIp, paediatric body adiposity index; FMI, fat mass index; FFMI, fat-free mass index; IMLC, index of metabolic load and capacity.
* Statistical significance.
† Adjustment for age; physical activity level; socio-economic condition and consumption of fruits, vegetables and legumes (healthy diet).
‡ Waist:height ratio, waist:hip ratio, android:gynoid ratio and regional IMLC were converted to *Z*-score.

1·54), android:gynoid fat ratio (PR = 1·46; 95 % CI 1·10, 1·93), trunk:leg fat ratio (PR = 3·63; 95 % CI 1·27, 10·37) and regional IMLC (PR = 1·38; 95 % CI 1·06, 1·80). In late adolescence (ages 17–19), the MONW phenotype was positively associated with waist circumference (cm) (PR = 1·06; 95 % CI 1·02, 1·10), WHtR (PR = 1·28; 95 % CI 1·02, 1·61) and WHR (PR = 1·32; 95 % CI 1·02, 1·72).

Discussion

In this study, conducted with normal-weight adolescents, the presence of the MONW phenotype was positively associated with anthropometric and body composition parameters indicative of central fat, such as waist circumference, WHtR, WHR, android/gynoid, trunk/leg and trunk:arm fat ratio, as well as with regional IMLC. The phenotype was also positively associated with FMI, indicative of total body fat. Thus, anthropometric and body composition measurements can be useful in the early diagnosis of normal-weight adolescents with high cardiometabolic risk.

The deposition of fat in the central or abdominal region, found in greater magnitude in the MONW adolescents of this study, is related to a higher risk of metabolic complications, mainly due to the accumulation of visceral fat[45,46]. This type of predominantly central or abdominal deposition, in the region of the thorax and abdomen, is characteristic of android obesity, also called truncal obesity[47].

Anthropometric measures have been used to identify central fat and cardiometabolic risk. These measures deserve to be highlighted in the context of clinical practice and epidemiological studies for measuring adiposity, given their better applicability, availability, safety, low cost and good correlation with adiposity[48,49]. In this sense, our findings agree with other studies[11,17] reporting that individuals with the MONW phenotype, despite having normal-weight by BMI, have higher waist circumference, which is a good marker of metabolic risk[50–52]. Besides, MONW had higher WHtR, an index that can be used to assess abdominal fat[52,53] and identify adolescents with high metabolic and cardiovascular risk[54], as well as higher WHR, used to assess body fat distribution and as an indicator of central obesity[52,53]. When considering the analysis stratified by age, we also found in adolescents aged 14 to 16 years a positive association of the phenotype with another measure indicative of central fat and cardiometabolic risk, the neck circumference.

The MONW phenotype was also positively associated with the regional IMLC in this study, which is an index that relates trunk fat to ALM, referring to visceral adiposity, associated with high morbidity and mortality from CVD[55]. The use of the IMLC helps to fill a gap in body composition studies, which is represented by the identification of individuals who present at the same time high adiposity and low muscle mass[32,56]. In this way, it is a model that demonstrates the metabolic imbalance in the individual, referring to the tissues that threaten the body's homoeostasis (fat) and those that maintain it (muscle)[32]. To our knowledge, this is the first study to identify this dysfunction of metabolic load and capacity in MONW adolescents.

Moreover, the MONW phenotype was positively associated with the FMI, which is an indicative index of total body fat that allows a more careful anthropometric evaluation of fat mass, according to body compartments, by calculation that considers height. Furthermore, when considering only female participants, we found an association of the MONW phenotype with BAIp, calculated by measuring the hip circumference and height, and which is also indicative of total body fat. Adipose tissue is capable of synthesising substances such as non-esterified fatty acids, hormones and pro-inflammatory cytokines – leptin, TNF and visfatin – that are related to the development of diseases[57,58]. The secretion of these substances by the adipose tissue, especially in the abdominal region, predicts

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Table 6. Association between anthropometric and body composition parameters with the MONW phenotype according to the stages of adolescence (Prevalence ratios and 95 % confidence intervals)

	Poisson regression with robust variance											
	Early adolescence (ages 10 to 13) (*n* 238)				Middle adolescence (ages 14 to 16) (*n* 123)				Late adolescence (ages 17 to 19) (*n* 145)			
	Crude model		Adjusted model†		Crude model		Adjusted model†		Crude model		Adjusted model†	
Measures	PR	95 % CI	PR	95 % CI	PR	95 % CI	PR	95 % CI	PR	95 % CI	PR	95 % CI
Waist circumference (cm)	1·04	0·99, 1·08	1·04	0·99, 1·09	1·04	0·99, 1·09	1·06	1·01, 1·12*	1·06	1·03, 1·10*	1·06	1·02, 1·10*
Waist:height ratio‡	1·20	1·00, 1·44	1·18	0·98, 1·43	1·30	0·99, 1·72	1·34	0·97, 1·86	1·12	0·89, 1·41	1·28	1·02, 1·61*
Waist:hip ratio‡	1·04	0·85, 1·27	1·10	0·88, 1·37	1·23	0·91, 1·67	1·24	0·87, 1·75	1·14	0·88, 1·48	1·32	1·02, 1·72*
Neck circumference (cm)	1·04	0·93, 1·16	1·05	0·91, 1·22	1·14	0·98, 1·32	1·25	1·01, 1·54*	1·06	0·96, 1·18	1·02	0·86, 1·21
Android/gynoid‡	1·28	1·09, 1·50*	1·30	1·10, 1·54*	1·38	1·06, 1·81*	1·46	1·10, 1·93*	1·32	1·08, 1·62*	1·26	0·99, 1·60
Trunk FM/Leg FM	2·96	1·36, 6·41*	3·26	1·47, 7·23*	2·30	0·84, 6·30	3·63	1·27, 10·37*	1·92	0·98, 3·76	1·41	0·62, 3·21
Trunk FM/Arm FM	1·11	1·01, 1·24*	1·14	1·02, 1·28*	1·07	0·90, 1·27	1·18	0·97, 1·43	1·10	0·98, 1·24	1·04	0·90, 1·21
BAIp	1·07	1·01, 1·13*	1·07	0·99, 1·15	1·03	0·97, 1·10	1·06	0·97, 1·17	0·98	0·92, 1·04	1·04	0·97, 1·12
FMI (kg/m²)	1·14	0·99, 1·31	1·13	0·97, 1·33	1·12	0·97, 1·29	1·19	0·98, 1·44	1·23	1·09, 1·40*	1·00	0·89, 1·13
FFMI (kg/m²)	1·06	0·91, 1·24	1·11	0·92, 1·34	1·01	0·86, 1·19	1·16	0·90, 1·49	1·08	0·97, 1·19	0·92	0·76, 1·12
Regional IMLC	1·28	1·07, 1·52*	1·31	1·10, 1·57*	1·22	0·95, 1·58	1·38	1·06, 1·80*	1·23	1·00, 1·52	1·12	0·86, 1·45

FM, fat mass; PR, prevalence ratio; BAIp, paediatric body adiposity index; FMI, fat mass index; FFMI, fat-free mass index; IMLC, index of metabolic load and capacity.
* Statistical significance.
† Adjustment for age; sex; physical activity level; socio-economic condition and consumption of fruits, vegetables and legumes (healthy diet).
‡ Waist:height ratio, waist:hip ratio, android:gynoid ratio and regional IMLC were converted to *Z*-score.

cardiometabolic alterations, insulin resistance, type 2 diabetes mellitus, metabolic syndrome and, consequently, CVD[59]. Thus, excess body fat is associated with increased cardiometabolic risk, and its early identification, especially in the younger population, is essential for the prevention of chronic diseases in adulthood. Thus, screening for excess body fat may be useful for the early diagnosis of MONW adolescents.

In this study, although we did not find an association between the MONW phenotype and lean mass indices, we emphasise that muscle mass is related to the metabolic profile. Skeletal muscle is the most abundant insulin-sensitive tissue in our body, in addition to being the primary site of glucose utilisation from the insulin-regulated glucose transporter (GLUT4), thus presenting a protective role against resistance to insulin and type 2 diabetes mellitus[60,61]. Furthermore, the secretion of myokines by skeletal muscle can positively interfere in the prevention of insulin resistance and inflammation[60].The fact that we did not find an association between the MONW phenotype and lean mass indices suggests a predominant effect of fat distribution on metabolic risk, exceeding the contribution of other parameters of body composition. However, the absence of observed association, added to the existing heterogeneity in the definition of phenotypes, in addition to the different ways of assessing muscle mass, indicates the need for further studies to clarify the role of this body compartment in predicting cardiometabolic risk in adolescents.

In this context, due to the high prevalence (29·1 %) of adolescents with the MONW phenotype found in this study, our results indicate that using only the BMI seems insufficient to determine cardiometabolic risk. Thus, the inclusion of measures of body fat – especially those indicative of central adiposity – in young people with normal weight will provide additional information and will help us to identify the MOWN phenotype, enabling an early intervention in order to reduce their possible cardiometabolic risk.

This study is not free of limitations. The cross-sectional design makes it impossible for us to ensure the temporality of the observed associations. Furthermore, there is no consensus on the concept of 'metabolic abnormality' for the classification of the MONW phenotype. However, it is valid to consider that due to the scarcity of studies with adolescents on this theme, the present study brought important contributions, especially for the nutritional assessment of this group. Moreover, it reinforces the importance of early detection of this phenotype, because for the young age group in question, having an alteration in cardiometabolic parameters, especially for the fact that they have normal-weight, already demonstrates concern about the health status of adolescents. Also noteworthy as positive points are the fact that this is a population-based study, the methodological rigor in data collection and the use of validated methods, such as DEXA. Furthermore, body composition indices adjusted for weight, BMI and height, as well as those that consider body compartments, which have been studied in differentiating the contribution of lean mass and adiposity in predicting disease risk, were evaluated.

Conclusion

The MONW phenotype associates positively with anthropometric and body composition measures indicative of central and total fat. Furthermore, the phenotype was positively associated with regional IMLC, revealing a metabolic imbalance of tissues and a threat to the body homoeostasis of MONW adolescents.

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B. C. C. was responsible for the analysis and interpretation of the data, conducted the literature search as well as wrote the manuscript. S. A. V. R. and L. L. J. participated in the analysis and interpretation of data as well as the critical review of the paper. S. E. P. acted in the conception and design of the study as well as the critical review of the paper. E. R. F. and F. R. F. participated in the conception of the study design, data collection as well as the critical review of the paper. P. F. F. participated in the conception of the study design, data collection and writing of the article. All authors have read and approved the final manuscript.

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