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ORIGINAL ARTICLE

Changes in adiposity status from childhood to adolescence: A 6-year longitudinal study in Portuguese boys and girls

Raquel Leitão[1,2], Luís Paulo Rodrigues[1,3], Luísa Neves[1] & Graça Simões Carvalho[2]

[1]*Polytechnic Institute of Viana do Castelo, Portugal,* [2]*Institute of Education, University of Minho, Portugal, and* [3]*Research Center in Sports Science, Health and Human Development, Portugal*

***Background*: Cross-sectional data show high prevalence of overweight in Portuguese children, but there are few longitudinal studies describing the patterns of obesity development in the young.**
***Aim*: To examine the trajectories of obesity from late childhood to adolescence.**
***Subjects and methods*: Triceps and subscapular skinfold thickness measurements were carried out in 288 children at age 9 (baseline) and later at age 15 (follow-up). Percentage body fat (%BF) was estimated according to Slaughter equations and the health-related definition of obesity ($\geq$ 25%BF in boys and $\geq$ 30%BF in girls) was used.**
***Results*: In boys, the prevalence of obesity decreased from 21.9% to 14.8% ($p < 0.05$) while in girls it increased from 14.3% to 19.5%. The incidence of obesity in the 6-year study period was 2.6% and 8.3% for boys and girls, respectively ($p < 0.05$). In comparison with girls, the percentage of boys that reversed obesity was more than 3-fold higher (3% vs 9.7%, $p < 0.05$). Obesity tracked moderately in both sexes (Kappa $= 0.6$, $p < 0.001$).**
***Conclusion*: The results indicate a marked sex difference in the incidence and reversal of obesity from late childhood to adolescence that is unfavourable to girls. Consideration of this difference might be important when designing programmes for the prevention and treatment of obesity focusing on this period.**

Keywords: Obesity, longitudinal study, childhood, adolescence

INTRODUCTION

Despite variations in different countries (Lissau et al. 2004; Yngve et al. 2007), it has been systematically reported that the prevalence of overweight and obesity among children and adolescents is increasing on a global scale (Speiser et al. 2005; Prentice 2006; James 2008). In Europe, especially in south-western countries, a tendency for a higher prevalence of overweight among school-aged youth has been noted (Lobstein and Frelut 2003; Janssen et al. 2005). Portugal seems to follow this trend, together with Spain, Greece, Italy and Malta (Lissau et al. 2004; Padez et al. 2004; Moreira 2007; Yngve et al. 2007).

Unless actions are taken to prevent childhood obesity from rising, we can predict a dramatic impact on public health and the economy since childhood obesity has strong possibilities to track into adulthood (Deshmukh-Taskar et al. 2006) and is associated with adverse health outcomes even in the young (Teixeira et al. 2001; Weiss et al. 2004; Korsten-Reck et al. 2008; Visness et al. 2009). To design successful preventive interventions it is essential to monitor and understand the current patterns of obesity development, with particular attention for periods of physiological change related to growth.

In Portugal we lack longitudinal approaches focused on the transition period from childhood to adolescence. Most of the existing data have resulted from cross-sectional studies and Body Mass Index (BMI) has been the common indicator used to determine the prevalence of overweight and obesity in all population groups (Moreira 2007). The use of BMI as a measure of adiposity in children and adolescents has important limitations due to the characteristic body composition changes that occur during growth (Prentice and Jebb 2001; Rodríguez et al. 2004) and, furthermore, it may under-estimate the prevalence of obesity (McCarthy et al. 2003).

Skinfold thickness measurement is an available non-invasive, inexpensive and adequate method to assess child and adolescent obesity (Norgan 2005). Changes in skinfold thickness or in percentage body fat (%BF) to monitor obesity have been considered less equivocal than BMI, thus providing greater confidence for epidemiological applications (Hughes et al. 1997; Sardinha et al. 1999; Olds et al. 2007). Moreover, it was recently reported that skinfold

Correspondence: Raquel Leitão, Escola Superior de Educação, Instituto Politécnico de Viana do Castelo, Avenida Capitão Gaspar de Castro, Apartado 513, 4901-908 Viana do Castelo, Portugal. Tel: 351 258 806 200. Fax: 351 258 806 209. E-mail: raquel.leitao@ese.ipvc.pt

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thickness during childhood and adolescence is a better predictor of high body fatness in adults than BMI (Nooyens et al. 2007; Taeymans et al. 2008).

Adolescence is a time of multiple physiological, psychological, social and behavioural changes. Although considered a high-risk period for obesity onset (Kimm et al. 2002; Dietz 2004), adolescence includes a rapid period of growth in which children may naturally reverse overweight. This is supported by the evidence that childhood obesity is moderately predictive of adult obesity (Guo et al. 1994). In fact, puberty is associated with a physiological decrease in %BF in boys. However, an opposite pattern characterized by an increase in %BF occurs in girls. These physiological changes may influence the patterns of obesity development, as previously suggested (Frelut and Flodmark 2002).

The purpose of this study was to examine the longitudinal changes in adiposity from late childhood to adolescence in a cohort of school-aged children. Obesity trajectories were identified, focusing on differences between sexes. The prevalence and incidence of obesity based on %BF derived from skinfolds were determined, as well as the proportion of children that maintained and reversed obesity as adolescents.

METHODS

Sample

Subjects in this study were schoolchildren enrolled in the EMCV study (*Estudo Morfofuncional da Criança Vianense*), which is an ongoing longitudinal study started in 1996 to investigate changes in growth and physical fitness (Rodrigues et al. 2006). The EMCV sample was selected on a voluntary basis from 15 primary public schools (all invited schools agreed to participate) located in the district of Viana do Castelo (northern Portugal). From a total of 435 children that formed the referred convenience sample, 299 (68.7%) underwent anthropometric assessment while attending fourth grade, in year 2000. Six years later, we searched again for these participants by consulting databases in every secondary school in Viana do Castelo. Anthropometric assessment was repeated. The present study included 288 students (155 boys and 133 girls) with valid anthropometric measurements at both baseline and follow-up assessments (66.2%). There were no significant differences in mean %BF between missing students and students who were followed-up (22.6 vs 19.9, respectively; $p = 0.3$), as well as in the other parameters. A balanced male/female (53.8 vs 46.2%) and urban/rural ratio (51.4% vs 48.6%) characterized this sample. Proportions representing different socioeconomic status, as indicating by parental educational levels, were the following: primary school, 22.8% and 17.3% for father and mother, respectively; secondary school, 69.0% and 74.9%; university, 8.3% and 7.8%. All children were White and their average age (standard deviation) was 9.0 (0.4) and 15.0 (0.4) years, respectively, in year 2000 (late childhood) and at follow-up in year 2006 (adolescence). There was no significant difference between the mean age of boys and girls. Before participation in the study each subject provided informed consent and written informed consent was obtained from parents or guardians. Procedures followed were in accordance with the Helsinki Declaration of 1975, as revised in 1983. The study protocol was approved by Direcção Regional de Educação (Regional Division of the Portuguese Ministry of Education) and authorized by the schools involved.

Measurements

Baseline data was collected at the Human Movement Laboratory of Viana do Castelo Polytechnic Institute from April to May 2000. The follow-up assessment was performed at eight public high schools located in the county of Viana do Castelo, during physical education classes from April to May 2006. Stature and weight were measured using standard procedures (Lohman et al. 1988) and BMI was calculated as weight (kg)/height(m)^2. Triceps and subscapular skinfold thickness was taken with a Harpenden calliper (British Indicators Ltd., UK) on the right side of the body according to the procedures recommended by Lohman et al. (1988). Each skinfold was measured three consecutive times and the average of three measurements was used for analysis. We tried to minimize as much as possible the measurement error because it could obscure underlying changes (Olds et al. 2007). Thus, the two first authors and one research assistant that went through a training process that included practice and comparison to one of the referred examiners took all anthropometric measurements. The mean difference between the two experiment examiners (first and second author) and the confidence interval (CI) on a sample of 10 subjects were as follows: triceps, 0.42 mm (95% CI: -0.21–1.05 mm) and subscapular, 0.16 mm (95% CI: -0.12–0.44 mm).

Body fat percentage derived from skinfolds was calculated by the formulae described by Slaughter et al. (1988), which were specifically developed for children and adolescents. It has been demonstrated that adiposity determined by Slaughter formulae is highly correlated with reference methods such as hydro-densitometry (Reilly et al. 1995), 4-compartment criterion model (Wong et al. 2000) or, more recently, dual energy X-ray absorptiometry (Steinberger et al. 2005).

Definition of obesity

The health-related definition of obesity ($\geq$ 25%BF in boys and $\geq$ 30%BF in girls) proposed by Williams et al. (1992) was used in the present work. Participants under the obesity cut-off point were classified as non-obese. Although the use of a single percentage fat value as a cut-off for classifying obesity has shown limitations due to %BF changes related to growth (Higgins et al. 2001), it is still considered to be appropriate if the study population does not include a wide age spectrum (Washino et al. 1999). Furthermore, Williams et al. (1992) established the above-mentioned cut-off points based on the association found with adverse cardiovascular risk factors. These %BF cut-off values were confirmed to represent good thresholds for metabolic health in a sample of lean and obese Portuguese children and adolescents (Teixeira et al. 2001). The new body fat reference curves for children represent an important break through on this matter, but the definition of cut-offs still lacks clinical correlation (McCarthy et al. 2006).

Statistical analysis

Descriptive statistics are presented as means, standard deviations, medians, quartiles and percentages. The normality of data distribution was evaluated separately for each assessment using the Shapiro-Will test. For the non-normally distributed variables (all with the exception of age and height), statistical differences between sexes were assessed by Mann-Whitney test and differences between baseline and follow-up by Wilcoxon test. For age and height, Student's t-tests were performed. Chi-square and McNemar tests were used to assess differences in categorical variables, respectively, between sexes and between assessments. Spearman correlations and Kappa statistics were calculated to examine the patterns of adiposity change and tracking of obesity over time. This was carried out separately for boys and girls. Tracking was defined as the correlation between measurements at age 9 and age 15 and as the maintenance of a certain status in the population over time (Twisk et al. 1994). If participants remained obese (or non-obese) during the study period, this was considered as tracking of obesity (or non-obesity). Tracking was defined as poor ($\kappa < 0.40$ or $r < 0.30$), moderate (κ between 0.40–0.75; r between 0.30–0.60) and high ($\kappa > 0.75$ or $r > 0.60$) (Landis and Koch 1977; Twisk et al. 1994). In order to assess the differences in tracking of adiposity measures and obesity status between sexes, z-tests for interaction were used. All statistical analyses were carried out using the SPSS version 17.0 software for Windows and the level of statistical significance was set as $p \leq 0.05$.

RESULTS

Baseline and follow-up values for each of the physical characteristics analysed are presented in Table I. At baseline, there were no significant differences in height, weight and BMI between sexes. However, girls had higher triceps skinfold thickness ($p < 0.001$), subscapular skinfold thickness ($p < 0.05$), sum of two skinfolds ($p < 0.001$) and %BF ($p < 0.05$) than boys. As expected, boys became significantly taller and heavier than girls ($p < 0.001$) at follow-up, but BMI maintained similar between sexes. At follow-up, similarly to the pattern observed at baseline, triceps skinfold thickness, subscapular skinfold thickness, sum of two skinfolds and %BF were significantly higher in girls than in boys. For subscapular skinfold thickness ($p < 0.001$) and %BF ($p < 0.001$) such differences became more pronounced at follow-up. Over the 6-year period from childhood (age 9) to adolescence (age 15), girls showed significant increases ($p < 0.001$) in all variables. In boys, there were also significant increases in weight, height, BMI, subscapular skinfold thickness ($p < 0.001$) and sum of two skinfolds ($p = 0.02$). In contrast to girls, boys showed a

Table I. Descriptive characteristics of participants at baseline and 6-year follow-up.

	Boys ($n = 155$)				Girls ($n = 133$)				p-values*			
	Baseline		Follow-up		Baseline		Follow-up					
	Mean (SD)	Median (Q1–Q3)	Mean (SD)	Median (Q1–Q3)	Mean (SD)	Median (Q1–Q3)	Mean (SD)	Median (Q1–Q3)	p^a	p^b	p^c	p^d
Age (years)	8.9 (0.4)	9.0 (8.5–9.5)	14.9 (0.4)	15.0 (14.5–15.5)	9.0 (0.4)	9.0 (8.5–9.5)	15.0 (0.4)	15.0 (14.5–15.5)	*0.000*	*0.000*	0.3	0.3
Weight (kg)	33.7 (7.5)	32.0 (28.5–38.0)	61.7 (12.7)	59.0 (54.0–77.0)	33.1 (6.9)	31.0 (28.0–37.0)	55.7 (9.8)	52.9 (49.5–60.7)	*0.000*	*0.000*	0.4	*0.000*
Height (cm)	135.5 (6.1)	135.8 (130.6–139.3)	170.0 (7.4)	170.1 (164.8–175.4)	134.7 (5.7)	134.4 (130.5–138.5)	160.6 (5.3)	160.7 (157.1–164.3)	*0.000*	*0.000*	0.3	*0.000*
BMI (kg/m^2)	18.2 (3.0)	17.4 (16.1–19.9)	21.2 (3.5)	20.3 (18.9–22.9)	18.1 (2.9)	17.3 (15.9–20.0)	21.6 (3.5)	20.8 (19.3–22.9)	*0.000*	*0.000*	0.9	0.2
Triceps (mm)	11.3 (5.4)	10.0 (7.0–14.0)	10.9 (5.2)	9.6 (7.7–13.1)	13.3 (5.1)	13.0 (9.0–17.0)	17.2 (5.0)	16.5 (13.9–20.2)	0.5	*0.000*	*0.000*	*0.000*
Subscapular (mm)	9.3 (7.0)	6.5 (5.0–11.0)	9.7 (4.8)	8.0 (6.9–10.9)	10.8 (6.8)	8.0 (6.0–12.5)	12.8 (5.4)	11.3 (9.3–14.1)	*0.000*	*0.000*	*0.01*	*0.000*
Sum of two skinfolds (mm)	20.6 (12.0)	16.5 (12.5–25.0)	20.7 (9.6)	16.9 (14.8–24.2)	24.1 (11.5)	21.0 (15.3–28.5)	30.1 (9.8)	27.6 (23.3–33.7)	*0.02*	*0.000*	*0.000*	*0.000*
Body fat (%)	18.9 (9.4)	16.1 (12.2–23.6)	17.7 (7.8)	14.8 (12.8–21.2)	21.0 (7.7)	19.7 (14.8–24.8)	25.4 (5.9)	24.3 (21.4–27.5)	*0.05*	*0.000*	*0.01*	*0.000*

SD, standard deviation. Q1, first quartile. Q3, third quartile.
*Mann-Whitney test and Wilcoxon test for comparison of all variables (except age and height for which student t-tests were used). [a] Differences between baseline and follow-up in boys; [b] Differences between baseline and follow-up in girls; [c] Differences between sexes at baseline; [d] Differences between sexes at follow-up. p-values in italics are statistically significant.

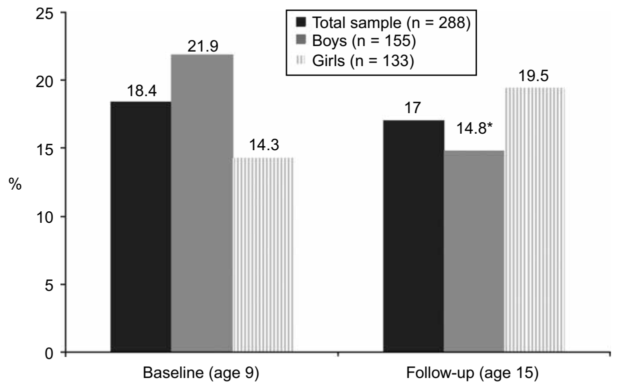

Figure 1. Difference between baseline and follow-up assessments for boys ($p < 0.05$).

decrease in %BF with age, but the difference was marginally significant ($p = 0.05$). There was no statistically significant difference in boys' triceps skinfold thickness between baseline and follow-up.

Overall, the prevalence of obesity was high at both baseline and follow-up assessments (Figure 1). Over the 6 years of follow-up there was a slight global decrease in the prevalence of obesity from 18.4% to 17.0%. A strong divergence in patterns of obesity prevalence was observed between boys and girls. At age 9, the percentage of obese boys was higher. Six years later, at age 15, these values were reverted, with girls presenting a higher prevalence of obesity. The increment of 5.2 percentage points in the prevalence of obesity in girls (from 14.3% to 19.5%) contrasted with a reduction of 7.1 percentage points in boys (from 21.9% to 14.8%, $p < 0.05$).

Table II shows the Spearman correlation coefficients between baseline and follow-up, calculated to examine the tracking of BMI, triceps skinfold thickness, subscapular skinfold thickness, sum of two skinfolds and %BF. Tracking coefficients ranged from 0.75–0.83 in boys and from 0.58–0.77 in girls, which is indicative of high tracking ($p < 0.01$) for all measures in both sexes, with the exception of triceps skinfold thickness in girls. There was no significant difference in the tracking of BMI between sexes. However, all the other variables tracked higher in boys than in girls (interaction z test, $p < 0.01$). In both boys and girls, BMI presented the highest level of tracking and the triceps skinfold thickness the lowest. Subscapular skinfold thickness, sum of two skinfolds and %BF tracked to a similar

Table II. Spearman correlation coefficients for each variable (tracking analysis).

	Boys ($n = 155$)		Girls ($n = 133$)	
	r	p	r	p
BMI	0.83	<0.01	0.77	<0.01
Triceps skinfold thickness	0.75*	<0.01	0.58	<0.01
Subscapular skinfold thickness	0.81*	<0.01	0.63	<0.01
Sum of two skinfolds	0.81*	<0.01	0.62	<0.01
%BF	0.81*	<0.01	0.62	<0.01

* Boys > girls (interaction z-test, $p < 0.01$).

extent within sexes. A modified Bland-Altman plot was constructed to illustrate the tracking of %BF separately by sex (Figure 2). As can be seen, the tracking of %BF is higher in boys than in girls, especially in those who tend to have less body fat at baseline (age 9). In addition, and also differently from the pattern in girls, the plot reveals that the greatest changes occurred in boys who had the greater adiposity at age 9.

To assess the tracking of adiposity status (obese or non-obese) from baseline to follow-up, we calculated Kappa coefficients (κ) for each sex. κ-values were 0.60 ($p < 0.001$) for boys and girls, revealing that adiposity status tracked moderately and to a similar extent in both sexes. Beyond reflecting the degree of stability, κ-values are also indicative of the extent of change. However, these coefficients do not provide information about the direction of change. Therefore we analysed trajectories of obesity from age 9 to age 15. Four trajectories were found: non-obese at both baseline and follow-up assessments (NO—NO), obese at both assessments (O—O), obese at baseline and non-obese at follow-up (O—NO) and non-obese at baseline and obese at follow-up (NO—O). Table III describes the number and proportion of children that followed each one of the referred trajectories. Of the 288 participants that formed the total sample, 220 subjects (76.4%) remained non-obese and 34 (11.8%) remained obese. Nineteen subjects (6.6%) reversed obesity while 15 subjects became obese. This last trajectory represents a global obesity incidence of 5.2% over the 6-year transitional period from childhood into adolescence. The analysis by sex showed no significant differences between the percentage of boys and girls following the NO—NO trajectory (75.5% vs 77.4%, respectively) and also the O—O trajectory (12.3% vs 11.3%). Fifteen of the 155 boys (9.7%) reversed obesity (O—NO), while only four of the 133 girls (3%) presented the same shift ($p < 0.05$). The incidence of obesity in girls was higher than in boys ($p < 0.05$), since 11 of the 133 girls (8.3%) and four of the 155 boys (2.6%) developed obesity (NO—O). Of the 235 participants classified as non-obese at age 9 years, 220 (93.6%) remained so as adolescents. In regard to the 53 participants classified as obese at baseline, it was found that 34 (64.2%) remained obese at follow-up. This means that during the study period the group of non-obese children was more stable than the group of obese children.

To better understand the dynamic changes in adiposity we analysed the development of percentage body fat by trajectory of obesity (Table IV). This procedure was undertaken separately for boys and girls. Boys' NO—O and girls' O—NO groups were too small to be included in the analysis of %BF changes between baseline and follow-up. For the same reason, the O—NO and NO—O trajectories were not considered in comparisons between sexes. From ages 9–15 years, boys who followed the NO—NO trajectory showed no significant change in %BF, while girls who remained non-obese presented a significant increase in %BF ($p < 0.001$). There were no significant differences in %BF between baseline and follow-up in both boys and girls who remained obese as adolescents (O—O). In boys who reversed

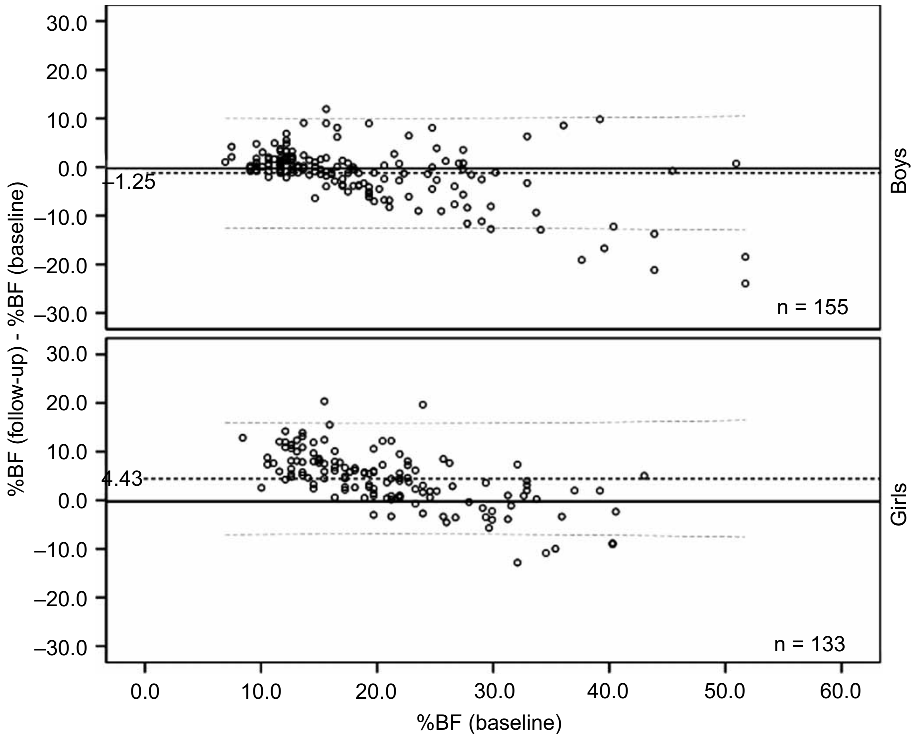

Figure 2. Modified Bland-Altman plot illustrating the tracking of %BF from age 9 (baseline) to age 15 (follow-up) by sex. The difference between %BF at follow-up and %BF at baseline is plotted against %BF at baseline. Black and grey broken lines represent means and 95% confidence intervals, respectively.

Table III. Trajectories of obesity. Values are number of participants and percentages.

	NO—NO		O—O		O—NO		NO—O	
	n	%	*n*	%	*n*	%	*n*	%
Total sample ($n = 288$)	220	76.4	34	11.8	19	6.6	15	5.2
Boys ($n = 155$)	117	75.5	19	12.3	15	9.7*	4	2.6*
Girls ($n = 133$)	103	77.4	15	11.3	4	3.0	11	8.3

NO, non-obese. O, obese. *Difference between sexes for O—NO and NO—O trajectories ($p < 0.05$).

obesity (O—NO) there was a significant decrease in %BF ($p = 0.001$) and a significant increase ($p < 0.05$) in %BF was found for girls who developed obesity (NO—O). At baseline, there were significant differences ($p < 0.001$) in %BF between sexes for the NO—NO trajectory but not for the O—O trajectory. At follow-up, sex differences in %BF were significant for both NO—NO ($p < 0.001$) and O—O trajectories, although, for the last, the difference was marginally significant ($p = 0.02$).

DISCUSSION

In this study we examined changes in adiposity and obesity development from late childhood (age 9) to adolescence (age 15). Height and weight changed as expected, with sex differences becoming evident at follow-up. While BMI behaved similarly between boys and girls, %BF presented a sexual dimorphism pattern that corresponds to the normal developmental changes in adiposity during adolescence. This demonstrates the known incapacity of BMI to distinguish between changes in %BF and changes in lean body mass (LBM) that occur in this period and differ between sexes. In boys, subscapular skinfold thickness increased significantly over time. Triceps skinfold thickness decreased, although not reaching a statistical significance and %BF decreased significantly. Therefore, it seems that compared to subscapular skinfold, triceps skinfold had a greater impact on boys' %BF development over this 6-year

Table IV. Percentage of body fat at baseline and follow-up by trajectory of obesity.

	Boys (n = 155)					Girls (n = 133)				
		Baseline		Follow-up			Baseline		Follow-up	
	n	Mean	SD	Mean	SD	*n*	Mean	SD	Mean	SD
NO—NO	117	14.6[a]	4.1	14.4[b]	3.7	103	18.2[d]	5.1	23.0	3.3
O—O	19	35.4	9.4	33.2[b]	8.3	15	35.7	4.0	35.9	4.7
O—NO	15	31.0[c]	5.6	20.3	2.6	4	33.3	1.9	23.9	3.4
NO—O	4	20.6	4.0	29.5	2.3	11	22.0[d]	4.2	33.7	3.7

NO, non-obese. O, obese. SD, standard deviation. [a] Difference between sexes at baseline for NO—NO trajectory ($p < 0.001$); [b] Difference between sexes at follow-up for both NO—NO ($p < 0.001$) and O—O ($p = 0.02$) trajectories; [c] Difference between baseline and follow-up assessments for O—NO trajectory in boys ($p = 0.001$); [d] Difference between baseline and follow-up assessments for NO—NO ($p < 0.001$) and NO—O ($p < 0.05$) trajectories in girls.

period. This suggests that in 9-year old boys there is already a tendency to accumulate and preserve fat mass predominantly in the trunk. In girls, there was a significant increase in %BF, together with significant increases in both triceps and subscapular skinfolds. However, triceps contributed to a greater extent to the rise in %BF than subscapular skinfold, indicating a preferential accumulation of fat in peripheral depots. Although not the focus of this investigation, these body fat distribution patterns, known as android and gynoid, are the most common patterns among males and females, respectively. Other studies have also found that sex differences in body fat distribution are present in children and adolescents (He et al. 2002; Shen et al. 2009). Despite these reported differences, a trend to central fatness has been observed in both boys and girls (Moreno et al. 2001). 'Central' or 'upper body' obesity is associated with a higher risk of metabolic disturbances (Bitsori et al. 2009).

The prevalence of obesity in this cohort was high at both baseline and follow-up assessments. Nevertheless, the results were much lower than the rates of obesity reported in two previous %BF-based studies on Portuguese children and adolescents (Sardinha et al. 1999; Teixeira et al. 2001). Inversely, when compared to data from national studies based on BMI, our results were markedly higher. While the present (%BF-based) prevalence of obesity is between 14–22%, in studies (BMI, IOTF-based) on Portuguese children at similar age, values range between 5–13% (Padez et al. 2004; Moreira 2007). Do the discrepancies really exist or do they rather result from the use of different measurements and definitions of obesity? This is clearly an important question because public health strategies must be developed according to the real extent and current trends of obesity. The use of different methods and definitions of childhood obesity has been shown to have a profound effect on the results displayed (Neovius et al. 2004). The variations can be considerable, as demonstrated in a study on Irish children in which the prevalence of obesity in boys ranged from 4.1–11.2% and in girls from 9.3–16.3%, depending on each one of the four weight-for-height methods of assessment used (O'Neill et al. 2007). In a study in 11–14 year old British adolescents (Potter et al. 2007), the prevalence of obesity based on %BF was more than 2-fold higher than that generated by BMI (12.5% vs 5.2%). For comparison, we have also determined the prevalence of obesity based on the IOTF sex- and age-specific BMI cut-off points. The results showed a great discrepancy between the estimates generated by the two obesity classification systems. When analysing changes in prevalence of obesity over time (from age 9–15 years) each method also revealed a different pattern. The prevalence of obesity based on %BF was more than twice as high as that obtained by BMI at age 9 (18.4% vs 7.6%, respectively, $p < 0.001$) and 4-fold higher at age 15 (17.0% vs 4.2%, $p < 0.001$). Overall prevalence for both obesity and overweight combined (BMI-based) was 30.5% and 20.5%, at baseline and follow-up, respectively. These values are similar to those reported in BMI-based studies in Portuguese samples and are also similar to the estimates from other Mediterranean countries.

Other methodological aspects such as the selection of children or the representativeness of the sample studied may also contribute to the disparity in the prevalence of obesity observed between studies. This emphasizes the difficulty on knowing the real dimension of obesity levels and how problematic comparisons between studies can be (O'Neill et al. 2007). Nevertheless, the above-mentioned differences between the prevalence of obesity based on BMI and %BF reinforce the possibility of BMI under-estimating the magnitude of this health problem in young people, as it has been suggested (McCarthy et al. 2003; Jebb et al. 2004; Potter et al. 2007).

The prevalence of obesity found in this study was not unexpected. It is well established that, along with increasing obesity in adults, there is increasing obesity among children and adolescents worldwide. Furthermore, despite showing lower levels than the US, some Mediterranean countries, including Portugal, appear to have particularly high prevalence rates of overweight and obesity in young people. However, we were expecting a higher prevalence of obesity in childhood compared to adolescence, since this pattern has been reported in several European countries like Spain, Greece, Germany, Poland, Czech Republic, Croatia, Russia and even outside Europe (China and Brazil) (Wang et al. 2002; Lobstein and Frelut 2003; Holmbäck et al. 2006; Serra-Majem et al. 2006; Georgiadis and Nassis 2007). Moreover, in a recent study in Portugal (Marques-Vidal et al. 2008) it was found that the prevalence of obesity in 10-year old children was markedly higher than in 15-year old adolescents. In the present study, although being longitudinal, the difference between the prevalence of obesity at age 9 years and age 15 years (18.4% vs 17.0%, respectively) was just 1.4 percentage points and thus not significant. Similar results were reported for young people in Great Britain (Jebb et al. 2004), but the values were based on the IOTF (International Obesity Task Force) BMI standards. A recent systematic analysis using a different definition of obesity also showed similar prevalence of at risk for overweight (BMI $\geq$ 85th percentile) or overweight (BMI $\geq$ 95th percentile) between older children and adolescents from the US (Wang and Beydoun 2007). This attempt to evaluate age-related patterns of obesity revealed it to be very difficult mainly because different age groups are combined together in many studies. One should also consider that under-estimation of obesity prevalence in adolescents is likely to occur to a greater extent when BMI is based on self-reported weight and height (Lissau et al. 2004; Janssen et al. 2005), a common practice in studies on large samples that can contribute to increase differences in the prevalence of obesity across ages.

Although the overall prevalence of obesity remained almost unchanged during the 6-year study period, the analysis by sex revealed important changes. There was a significant decrease in the prevalence of obesity in boys while there was an increase in girls. At baseline (age 9), boys had higher prevalence of obesity than girls, but the difference did not reach statistical significance. Similar results have been reported (Padez et al. 2004; Serra-Majem et al. 2006; Yngve et al. 2007), while opposite observations (Magarey et al. 2001) or no sex differences have been found in children aged ~ 9 years (Jebb et al. 2004; Georgiadis and Nassis 2007; Marques-Vidal et al. 2008). At follow-up (age 15), the prevalence of obesity was higher for girls. From a cross-sectional perspective, once again this is consistent with the results of some studies (Al-Sendi et al. 2003; Potter et al. 2007), but not others (Jebb et al. 2004; Serra-Majem et al. 2006). Contrasting results between sexes were also found in a comparison between 21 surveys in Europe (Lobstein and Frelut 2003). In the referred study, the number of countries in which girls had a greater overweight prevalence than boys was virtually the same as the number of countries in which the opposite was observed. Based on these data no clear sex or age pattern can be stated.

Examining the tracking of obesity during growth is of particular importance because it can help in targeting prevention or treatment interventions at specific periods where it is most likely to be effective. As far as we know, this is the first study in Portugal that describes the tracking of obesity during the transition to adolescence. Consequently, we were unable to make comparisons with Portuguese samples. Like previously found in a longitudinal study of young people in Britain (Wardle et al. 2006), the tracking of BMI was high and its magnitude did not differ significantly between sexes. For skinfold thicknesses and %BF, the tracking levels in girls were significantly lower than in boys. Triceps exhibited the lowest tracking of all measures within each sex and in girls it tracked only moderately. The fact that the tracking of BMI did not differ significantly between sexes, opposite to the significant differences found for the other variables, demonstrates the incapacity of BMI to distinguish increasing LBM from decreasing %BF that occurs simultaneously in boys. In girls, there is a physiological increase in %BF and in LBM, although the LBM development is not as rapid and great as it is in boys (Frelut and Flodmark 2002). Also, the lower tracking found for skinfolds and %BF in girls in comparison to boys is indicative of greater changes in adiposity. It is possible that this difference might be related to sex differences in pubertal development. Although we have tried to minimize this effect by assessing participants at age 9 and age 15, no measure of pubertal development was included in the present study. This is a limitation for interpreting the results since it has been suggested that precocious puberty may be associated with high adiposity in young girls (Davidson et al. 2003). Nevertheless, the high tracking found for most measures in both sexes represents a significant predictive value. At least partially, this is due to the stability of the natural development of body weight.

The moderate tracking found for obesity confirms the above consideration and shows that stability and change occurred to similar extents. In contrast to the tracking found for most adiposity measures, there was no sex difference in the degree of tracking of obesity. Comparison between studies on tracking of obesity is difficult because it involves high methodological variability. In addition to the measure of adiposity and cut-off used to define obesity, the degree of tracking also depends on the age of initial assessment and length of follow-up. We found no studies with a combination of characteristics similar to that in the present study. In a 6-year follow-up study from childhood to adolescence in China (Wang et al. 2000), it was reported that overweight (based on BMI) tracked in boys more consistently than in girls and the overall tracking pattern of obesity was weak. Among several factors, the authors pointed to the use of the IOTF standard as one possible explanation for the low tracking found. In a short-term (2-year follow-up) study in Greek children (Psarra et al. 2005) it was found that obesity, also defined by the IOTF criteria, tracked more in boys than in girls, but the overall tracking was high.

The 6-year incidence of obesity in the present study was more than 3-fold higher in girls than in boys. Moreover, a considerable proportion of boys reversed obesity, although only a few reversals occurred in girls. The fact that the obese group was the less stable of the two baseline groups (non-obese/obese) was mainly due to the large number of boys that became non-obese ($n = 15$). These findings suggest that the sex-related physiological changes in %BF may have contributed to the apparent increased risk of development of obesity in girls while offering some 'protection' in boys. The marked sex difference in the incidence and reversal of obesity observed in this study emphasizes the importance of recognizing growth periods as both vulnerable periods for the development of obesity and windows of opportunity for successful interventions. These results are consistent with other studies that indicate that males reverse more than females (Garn and Cole 1980) and reveal increasing prevalence of obesity in girls during adolescence (Kimm et al. 2002). However, in a longitudinal study of young people in Britain, the incidence and remission rates of obesity during adolescence were low in both boys and girls (Wardle et al. 2006). Therefore, the extent to which the physiological changes in body fat contribute to the susceptibility for the development of obesity should be further investigated.

Despite the marked sex differences in the incidence and remission rates of obesity found in the present study, the percentage of boys that remained obese as adolescents was similar to the percentage of girls that followed this same trajectory. In addition, the %BF growth by trajectory of obesity and by sex suggests that it is possible that boys and girls in this sample may become similarly vulnerable to developing obesity as they reach adulthood. See, for example, the absence of a significant decrease in %BF for boys that followed the NO—NO trajectory. In fact, previous research on the transition to adulthood has found a very high proportion of both male and female adolescents becoming and remaining obese (Gordon-Larsen et al. 2004).

In the present investigation, skinfolds were chosen as the variable of interest because: (1) they assess adipose tissue mass, the component of excess weight that is associated with co-morbidities (Fortuño et al. 2003); (2) they correlate well with body fatness when compared to reference methods (Liem et al. 2009), being an adequate alternative for monitoring obesity in children and adolescents (Hughes et al. 1997; Nooyens et al. 2007); (3) BMI percentile changes may not accurately reflect changes in adiposity in children over time (Demerath et al. 2006); and (4) there is little longitudinal data for skinfold thickness and %BF changes in Portuguese children and adolescents (Moreira 2007).

Like in most longitudinal studies, a limitation of this study was that there were losses to follow-up, mainly due to changes in address. However, none of the anthropometric and body composition parameters was significantly different between followed and non-followed students. Nevertheless, the results from this study are limited to a specific setting and therefore further studies are required for a confirmation at national scale.

CONCLUSION

The longitudinal approach in this study helped us to better understand the origin of adolescent obesity, for which there is one of the following possibilities: (i) incidence of obesity in adolescence; (ii) tracking of obesity from childhood; or (iii) a combination of both. In boys, late childhood was a critical period because of the tracking of obesity. In girls, both late childhood and adolescence represented critical periods because of, respectively, tracking and incidence of obesity. The results indicate marked sex differences in the incidence and reversal of obesity from childhood to adolescence that are more unfavourable to girls. Consideration of these differences might be important when designing programmes for the prevention and treatment of obesity focusing this period.

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