A five year longitudinal study investigating the prevalence of childhood obesity: comparison of BMI and waist circumference

Corresponding author	Dr. Claire Griffiths C.Griffiths@leedsmet.ac.uk	Senior Lecturer in Physical Activity, Exercise and Health Institute for Sport, Physical Activity and Leisure Leeds Metropolitan University Fairfax Hall Headingley Campus Leeds LS6 3QS Tel - 0113 812 6566 Mobile - 07834457344
Additional authors	Professor Paul Gately P.Gately@leedsmet.ac.uk	Professor of Exercise and Obesity Leeds Metropolitan University Churchwood Hall Headingley Campus Leeds LS6 3QS
	Dr. Paul R Marchant P.Marchant@leedsmet.ac.uk	Visiting Fellow in Statistics Leeds Metropolitan University Caedmon Hall Headingley Campus Leeds LS6 3QS
	Professor Carlton B Cooke C.Cooke@leedsmet.ac.uk	Professor of Sport and Exercise Science Institute for Sport, Physical Activity and Leisure Leeds Metropolitan University Fairfax Hall Headingley Campus Leeds LS6 3QS

Abstract

Objective: The purpose of this study was to examine the prevalence of obesity over time in the same individuals comparing body mass index (BMI), waist circumference (WC) and waist to height ratio (WHtR).

Study design: Five year longitudinal repeated measures study (2005 – 2010). Children were aged 11-12 (Y7) years at baseline and measurements were repeated at age 13-14 (Y9) years and 15-16 (Y11) years.

Methods: WC and BMI measurements were carried out by the same person over the five years and raw values were expressed as standard deviation scores (sBMI and sWC) against the growth reference used for British children.

Results: Mean sWC measurements were higher than mean sBMI measurements for both sexes and at all assessment occasions and sWC measurements were consistently high in girls compared to boys. Y7 sWC = 0.792 [95% confidence interval (CI) 0.675–0.908], Y9 sWC = 0.818 (95%CI 0.709-0.928), Y11 sWC = 0.943 (95%CI 0.827-1.06) for boys; Y7 sWC = 0.843 (0.697-0.989), Y9 sWC = 1.52 (95%CI 1.38-0.67), Y11 sWC = 1.89 (95%CI 1.79-2.04) for girls. Y7 sBMI = 0.445 (95%CI 0.315-0.575), Y9 sBMI = 0.314 (95%CI 0.189-0.438), Y11 sBMI = 0.196 (95%CI 0.054-0.337) for boys; Y7 sBMI = 0.353 (0.227-0.479), Y9 sBMI = 0.343 (95%CI 0.208-0.478), Y11 sBMI = 0.256 (95%CI 0.102-0.409) for girls. The estimated prevalence of obesity defined by BMI decreased in boys (18%, 12% and 10% in Y 7, 9 and 11 respectively) and girls (14%, 15% and 11% in Y 7, 9 and 11). In contrast, the prevalence estimated by WC increased sharply (boys; 13%, 19% and 23%; girls, 20%, 46% and 60%).

Conclusion: Central adiposity, measured by WC is increasing alongside a stabilisation in BMI. Children appear to be getting fatter and the additional adiposity is being stored centrally which is not detected by BMI. These substantial increases in WC are a serious concern, especially in girls.

Children, obesity, central obesity, BMI, waist circumference, longitudinal

Introduction

Childhood obesity has become a major public health concern. Obese children have an increased risk of developing health, psychological and social problems (1) and are more likely to be obese in adolescence and adulthood (2, 3). In addition to affecting personal health, the increased health risks translate into an increased burden on the health care system and the economy.

Recent publications from a number of countries (4), including the UK (5, 6), suggest there has been a levelling off in overweight and obesity prevalence occurring in the child population as a whole, or in certain subgroups of it. However, the most up to date cross-sectional prevalence data does not provide encouragement that public health targets aimed at reducing obesity can be met. On average, 13.3% and 14.6% of children in reception (aged 4-5) and year 6 (aged 11-12) respectively are overweight and a further 9.8% and 18.7% are obese (5).

A major concern with the current evidence base is that it relies solely on the use of BMI to determine obesity and is predominately cross-sectional. There is emerging evidence to suggest that central obesity is increasing at a faster rate than BMI (7-9) and concern should be raised in light of the increased health risks associated with central obesity in childhood (10-13). Furthermore, relying solely on cross-sectional prevalence data does not provide any insight on the duration of obesity.

This paper builds on the recently published, cross-sectional data from the Rugby League and Athletics Development Scheme (RADS) (6) comparing the prevalence of obesity estimated by three different measures of adiposity, body mass index (BMI), waist circumference (WC) and waist-to-height-ratio (WHtR), using a longitudinal design over 5 years.

Methods and procedures

The Rugby League and Athletics Development Scheme (RADS) is a collaboration between Leeds City Council (LCC), Leeds Metropolitan University and the Education Authority (Education Leeds - EL). Ethical clearance was granted by the Ethics Committee of the Carnegie Faculty, Leeds Metropolitan University.

Cross sectional data from the RADS programme has been reported previously (6). All secondary schools in Leeds were invited to take part in the programme which was aimed at children in their first year of secondary school (age 11-12 years). The purpose of the programme was to identify talented children who were not engaged in sport outside of school. All 33 schools that participated in the original cross sectional programme (6) were invited to participate in the follow up however, only 7 schools agreed to participate. Although the participation rate at a school level was lower than anticipated (7 from 33 schools), participation at an individual level (i.e. children from the 7 schools that participated in the longitudinal follow up) remained high in line with the cross sectional data collection (6) (> 90% at each measurement occasion in each of the 7 schools).

Data collection started in September 2005 when the children were in Y 7 (aged 11-12 years). Measurements were then repeated in January 2008 when the children were in Y9 (aged 13-14 years) and finally in January 2010 when the children were in Y11 (aged 15-16 years). Therefore, the time interval between measurements may vary slightly. All children consenting from the seven schools were eligible to take part, however, only children with at least 2 measurements were included in the analysis. In total 336 (45%) children had all measurements from all three years of data collection (i.e. ‘complete data’ allowing a direct comparison of exactly the same pupils over all 3 assessment occasions). However an additional 410 (55%) children had at least two measurements (Y7 and Y9 n=254 (34%); Y7 and Y11 n=87 (12%); Y9 and Y11 n=69(9%)) resulting in 746 children used in the final analysis (i.e. mixed data). Sensitivity analysis showed that using just the complete data did not substantively alter overall conclusions.

Information on children who were not measured as part of the programme was not obtained. However, it should not be assumed that those not providing data opted out for example, children may have been absent from school on the testing day.

Due to the low numbers of children in ethnic groups other than White British it was not possible to allow comparisons between ethnic groups.

Measures

Body mass was measured in kilograms (kg) using manually calibrated electronic scales (Tanita TBF-310 Tanita Corp., Tokyo, Japan). Children wore light indoor physical education clothing without shoes and were instructed to stand on the scales with their weight distributed evenly between both feet (14). Stature was measured to the nearest 0.1cm using a floor-standing Leicester height measure (model 220) (15). Waist circumference (WC) was measured mid-way between the 10th rib and the iliac crest (8, 16) in a horizontal (transverse) plane to the nearest 0.1 cm using an inelastic tape, with the children in a standing position wearing a thin t shirt. To allow for clothing 0.5cm was subtracted from the waist circumference measurement (8) and this resulting value is used in analyses. All testing took place on school premises and all measurements were carried out by the same person (CG).

BMI measurements were standardised (sBMI) for age and sex with the British 1990 growth reference charts (UK90) (17). WC measurements were standardised (sWC) for age and sex using the published reference based on the data from the British Standards Institute survey

(18). Standardised measurements were calculated using the conversion programme obtained from the Child Growth Foundation (19, 20) for the UK90 growth reference curves, which were designed so as to have a mean of zero and a standard deviation of 1 at each age. Waist-to-height ratio (WHtR) was calculated as WC (cm) / stature (cm). Children were classified as obese based on their sBMI and sWC to allow comparison while accounting for normal growth. The 95th reference centile (standardised score = 1.64) was used to define obesity for these two and a WHtR exceeding 0.5 was used to define obesity (12, 21).

Statistical Analysis

The prevalence of obesity was calculated as a percentage of those exceeding the reference threshold and binary logistic, repeated measures Multi-Level Models (MLM) were used to investigate obesity prevalence over time using the MLwiN program *(MLwiN. Bristol. UK*). Measurement year (i.e. year 7, 9 and 11) was included at level 1 and pupils were included in the model at level 2. In multi-level structures balanced data are not required to obtain efficient estimates (22), i.e. with repeated measures it is not necessary to have the same number of measurement occasions (level 1) per individual (level 2). With MLM all of the available data can be incorporated into the analysis, thereby maximising the use of available data. Furthermore, MLM gives estimates of the variability of the level 2 units which can also depend on level 1 variables. The effect of the fixed effect predictors ($B_0 – B_3$ in the model) were seen to be very similar when fitting models of the same form using Generalized Estimating Equations (GEEs) another technique for dealing with inherent clustering as in repeated measures within individuals, providing confidence in the results from this analysis.

The MLM were fitted used using Maximum Likelihood Estimation. Testing year was included as a discrete variable (0, 1, 2) for simplicity of reporting results. It was treated as a linear relationship. Comparison of the same models with testing year treated as a categorical variable was considered and resulted in the same substantive overall conclusions. Gender was included in the model as an interaction term with testing year to investigate if its effect changes as the children get older. The alpha level adopted for statistical significance was $p < 0.05$ i.e. absolute value of the coefficient if 1.96 times the SE.

Results

Table 1 shows descriptive statistics for raw anthropometric measurements and the associated standardised BMI and WC measurements (sBMI and sWC respectively). Based on the fact that the children are growing, one would expect to observe significant increases in the mean of raw measurements. Mean sWC measurements are higher for both sexes than mean sBMI measurements and higher in girls compared to boys at all three assessment occasions, which is in agreement with recent published cross sectional data from the Health Survey for England (9)

The changes in the mean sWC for girls increased from the 79th centile (sd score = 0.84) of the reference population to the 97th (sd score = 1.89) centile between the ages of 11 – 16 years. Mean sWC for boys increased from the 78th (sd score = 0.79) centile of the reference population to the 82nd (sd score = 0.94) centile between the ages of 11 – 16 years.

Prevalence of obesity over time

Figure 1 shows the sample prevalence rates of obesity estimated by sBMI, sWC and WHtR for boys and girls separately. The three measures show considerably different patterns and there appears to be a difference between boys and girls. The estimated prevalence of obesity defined by sBMI is decreasing albeit it slightly, in boys (18%, 12% and 10% in year

7, 9 and 11 respectively) and girls (15%, 15% and 11% in year 7, 9 and 11). The prevalence estimated by sWC increases sharply between the measurement years. This pattern is supported by the results of MLM (table 2). The increase for girls is marked, such that by year 11 (aged 15-16 years) 60% of girls are obese by this measure, compared to 23% of boys. The prevalence of obesity estimated by WHtR lies between the estimates based on sWC and sBMI. However, the trends observed for boys and for girls are in different directions (i.e. the trend for boys is decreasing whilst that for girls increases).

Logistic multilevel models agree with the patterns observed (Table 2). The multilevel model included gender (reference = boy), and a testing year (linear) coefficient, and an interaction between testing year and gender. This enables a straight line over time logit prediction for boys and girls with different intercepts and different slopes. The prevalence of obesity estimated by sBMI is actually decreasing over time (per 2 school years between measurement points) (coefficient = -0.349 SE = 0.129) for boys but the additional increment of rate of change for girls is not significant (coefficient = 0.290 SE = 0.178). Obesity prevalence for boys estimated by sWC is significantly increasing over time (coefficient = 0.350 SE = 0.112) and the additional increase in girls is considerable (coefficient = 0.603 SE = 0.148). A flat trend is observed in the prevalence of obesity estimated by WHtR for boys (coefficient = -0.166 SE = 0.120) whereas for girls the additional increment shows an increasing trend (coefficient = 0.629 SE = 0.163).

Discussion

Results show that the different measures of adiposity result in different findings, which is in agreement with cross sectional data (6, 8, 9). The prevalence of central obesity, measured by sWC is considerably higher than estimates based on sBMI and is increasing over time, especially in girls. Perhaps more importantly, this trend in sWC is observed alongside a stabilisation in sBMI in the same children over the same time period. Large cross sectional studies (6, 8, 16) have previously shown that trends in WC greatly exceed those in BMI, in children. However, the RADS data is the first to investigate this important issue using a longitudinal design and it seems that the proportion of fat deposited centrally rather than peripherally is increasing as children get older, especially in girls.

Furthermore, measured WC values from the RADS data at each centile, for both genders in all age groups, are considerably higher compared to the measured WC values from the reference data (18) see Table 3. The biggest shifts are observed in girls as they get older, which is supported by previous cross sectional data (8, 9, 16) and longitudinal data (7). What is perhaps more concerning from the comparisons in table 3 is that by age 14 almost 25% of the girls from the RADS data exceed adult cut points for increased risk (88cm) and 10% exceed adult cut points for obesity (88cm).

Many studies of the change in the prevalence of obesity in children concentrate on BMI, in line with national recommendations (23). The longitudinal RADS data does offer some cause for optimism at the local level. The stabilisation observed based on sBMI is a rare piece of good news and supports numerous cross sectional publications (4, 6). However, we believe this is the most up to date data to compare obesity prevalence trends estimated by BMI, WC and WHtR in the same children from a longitudinal design and the results show that the increase in WC is substantial and is likely to be greater than that for BMI. Which is in agreement with cross sectional data from the Health Survey for England (9). Suggesting that relying on BMI as an estimate of obesity may not capture the real picture.

From a public health perspective the stabilisation in general obesity estimated by sBMI could be viewed as promising, as efforts to tackle obesity may have resulted in an environment that is less permissive to obesity (although there are no formal evaluations to support this).

However, these longitudinal data place these ‘positive’ trends in a different light, because very few obese children actually lose weight to become a healthy weight between the ages of 11-16 years. This is even more worrying when sWC data is considered, as the prevalence of central obesity estimated by sWC actually continues to increase between childhood and adolescence, regardless of the observed stabilisation in sBMI. It seems that the contemporary obesity epidemic is characterised by an early onset and longer exposure to obesity than perhaps previously thought. Furthermore it seems that the additional adiposity is being stored centrally.

It is important to acknowledge that the three measures are looking at different aspects of obesity, which may in part explain the differences in the patterns observed. BMI is an indirect measure of general adiposity (it only measures stature and mass not adiposity directly), whereas WC is a surrogate measure of central adiposity, and when measured in conjunction with stature (WHtR) gives and index of proportionally. Research has demonstrated that WC offers no advantages over BMI in predicting general adiposity (or total body fat) (24, 25) however, WC has been shown to be superior to BMI in predicting central adiposity in children (13, 26). A major drawback of only considering total body fat (i.e. BMI) is that it gives no indication of body fat distribution, and it has been known for some time that a central distribution of body fat carries a higher risk for obesity related ill health in adults and children (27-31). BMI and WC interact in a complex fashion, especially during childhood and studies that have compared measures of adiposity, including this one, show that there is a wide variation in body fatness within subjects with the same BMI. Furthermore, this data suggests that changes in BMI (or general fatness) do not reflect changes in central adiposity. As separate measures of fatness BMI, WC and WHtR have been shown to perform well (32) however, as measures of risk they can lead to different interpretations. Conclusions linking BMI, WC and WHtR as measures of obesity to health risk cannot be drawn from this data. However, the findings do have implications for public health. Relying on BMI alone may conceal differences in body composition, especially central adiposity, therefore provide inaccurate estimates of obesity prevalence and the associated health risks.

Although there is an emerging evidence base to suggest that central adiposity in children is more relevant to health outcomes than overall adiposity estimated by sBMI (10-12, 29-31, 33), it is not yet possible to estimate the impact of the increase in sWC on current and future morbidity, but such increases should be a cause for concern. Most shocking is the fact that by the time the children reach 15-16 years 25% of the girls exceed adult cut points (23) for overweight (80cm) and 10% actually exceed the adult cut points for obesity (88cm). This can be considered a robust finding given that these adult cut points have the most evidence in relation to future health risk (23). This would not have been detected by sBMI or WHtR prevalence estimates alone. Of the 25% of girls with a WC exceeding 80cm, 26% had a WHtR < 0.5 and 62% were not obese according to their sBMI. Likewise for those girls with a WC exceeding 88cm, 13% had a WHtR <0.5 and 32% were not obese according to their BMI. Closer monitoring of WC, particularly in longitudinal studies with long-term follow up of individuals, are required.

This study is not without limitations. Firstly, there is considerable concern with the use of standardised WC measurements in children, and so these findings should be interpreted in light of the potential limitations of the standardisation process for WC in children (18). The author of these charts (18) suggests that they should be validated against longitudinal data, because that they do not know if they accurately adjust for growth changes. One conclusion from these data may be that they do not. It is possible therefore that the prevalence figures (estimated by WC) shown in figure 1 are overestimated and so should be interpreted with caution. However, comparison of the actual measured WC values (i.e. not subject to the statistical draw backs of the standardisation process) from the RADS data and the reference data (table 3) support the overall findings, that WC is increasing as children get older and this increase is marked in girls. Furthermore, cross sectional data report similar gender disparities (9).

Secondly this study is based on one city in the north east of England and has a modest sample size over the five years and so is not generalizable to the population of England. However, the results are in agreement with National cross sectional data (9) which are generalisable to the general population of the UK.

Finally, it would interesting to investigate the prevalence of obesity and the shift in BMI and WC distributions over the study period by ethnicity. Body composition, particularly visceral adiposity, varies by ethnicity and so this may affect the interpretation and this becomes of greater significance in adulthood.

Conclusion

Regardless of the measure used to determine obesity the proportion of obese children, has never been larger than it is today. Although the conclusion that childhood obesity prevalence estimated by sBMI is stable may be welcome news, the increase in WC and WHtR is a concern; incidence rate and duration of central obesity estimated by sWC are increasing alongside a stabilisation in sBMI. Children appear to be getting fatter with the additional adiposity being stored centrally, especially in girls. It is therefore possible that the health burden associated with obesity may be higher than expected, regardless of the observed stabilisation in prevalence estimated by sBMI.

Acknowledgement

We would like to thank Leeds City Council and Carnegie Weight Management for their initial collaboration in establishing the programme. In addition we would like to thank Leeds City Council and the secondary schools that participated in the programme for providing the data from the rugby league and athletics development scheme (RADS).

Funding – None

Competing interests – none declared

1. Summerbell CD, Waters E, Edmunds LD, Kelly S, Brown T, Campbell KJ. Interventions for preventing obesity in children. Cochrane Database of Systematic Reviews. 2005(3):CD001871.
2. Centre for Longitudinal Studies. Millennium Cohort Study: Childhood Obesity. Institute of Education, London; 2007.
3. Power C, Lake JK, Cole TJ. Measurement and long-term health risks of child and adolescent fatness. International Journal of Obesity Related Metabolic Disorders 1997 Jul;21(7):507-26.
4. Olds T, Maher C, Zumin S, Peneau S, Lioret S, Castetbon K, et al. Evidence that the prevalence of childhood overweight is plateauing: data from nine countries. International Journal of Paediatric Obesity. 2011 Oct;6(5-6):342-60.
5. The NHS Information centre. National Child Measurement Programme: England, 2009/10 school year.: Stationary office, London.; 2010.
6. Griffiths C, Gately P, Marchant PR, Cooke CB. Cross-Sectional Comparisons of BMI and Waist Circumference in British Children: Mixed Public Health Messages. Obesity. 2012 Jun;20(6):1258-60.
7. Wardle J, Brodersen NH, Cole TJ, Jarvis MJ, Boniface DR. Development of adiposity in adolescence: five year longitudinal study of an ethnically and socioeconomically diverse sample of young people in Britain. British Medical Journal. 2006 May 13;332(7550):1130-5.
8. McCarthy HD, Ellis SM, Cole TJ. Central overweight and obesity in British youth aged 11-16 years: cross sectional surveys of waist circumference. British Medical Journal. 2003 Mar 22;326(7390):624.
9. Mindell JS, Dinsdale H, Ridler C, Rutter HR. Changes in waist circumference among adolescents in England from 1977-1987 to 2005-2007. Public Health. 2012 Aug;126(8):695-701.
10. Zimmet P, Alberti G, Kaufman F, Tajima N, Silink M, Arslanian S, et al. The metabolic syndrome in children and adolescents. Lancet. 2007 Jun 23;369(9579):2059-61.
11. Schmidt MD, Dwyer T, Magnussen CG, Venn AJ. Predictive associations between alternative measures of childhood adiposity and adult cardio-metabolic health. International Journal of Obesity, . 2010 Sep 28.
12. Freedman DS, Kahn HS, Mei Z, Grummer-Strawn LM, Dietz WH, Srinivasan SR, et al. Relation of body mass index and waist-to-height ratio to cardiovascular disease risk factors in children and adolescents: the Bogalusa Heart Study. American Journal of Clinical Nutrition. 2007 Jul;86(1):33-40.
13. Savva SC, Tornaritis M, Savva ME, Kourides Y, Panagi A, Silikiotou N, et al. Waist circumference and waist-to-height ratio are better predictors of cardiovascular disease risk factors in children than body mass index. International Journal of Obesity Related Metabolic Disorders. 2000 Nov;24(11):1453-8.
14. The NHS Information Centre. The National Child Measurement Programme. Guidance for PCTs: 2007-08 school year. Stationary Office, London; 2007.
15. Lohman T, Roche A, Martorell R. Anthropometric Standardisation Reference Manual: Human Kinetics; 1998.
16. McCarthy HD, Jarrett KV, Emmett PM, Rogers I. Trends in waist circumferences in young British children: a comparative study. International Journal of Obesity, . 2005 Feb;29(2):157-62.
17. Cole TJ, Freeman JV, Preece MA. Body mass index reference curves for the UK, 1990. Archive of Disease in Childhood. 1995 Jul;73(1):25-9.
18. McCarthy HD, Jarrett KV, Crawley HF. The development of waist circumference percentiles in British children aged 5.0-16.9 y. European Journal of Clinical Nutrition,. 2001 Oct;55(10):902-7.

19. Child Growth Foundation. UK cross sectional reference data: 1990/1. London: Child Growth Foundation; 1996.
20. Child Growth Foundation. Microsoft Excel add-in to access growth references based on the LMS method. London2007.
21. McCarthy HD, Ashwell M. A study of central fatness using waist-to-height ratios in UK children and adolescents over two decades supports the simple message--'keep your waist circumference to less than half your height'. International Journal of Obesity, . 2006 Jun;30(6):988-92.
22. Rasbash J, Steele F, Browne W, Prosser B. A User's Guide to MLwiN: London Institute of Education; 2005.
23. National Institute for Health and Clinical Excellence. Obesity: guidance on the prevention, identification and assessment and management of overweight and obesity in adults and children. 2006.
24. Glasser N, Zellner K, Kromeyer-Hauschild K. Validity of body mass index and waist circumference to detect excess fat mass in children aged 7-14 years. European Journal of Clinical Nutrition,. 2011 Feb;65(2):151-9.
25. Reilly JJ, Dorosty AR, Ghomizadeh NM, Sherriff A, Wells JC, Ness AR. Comparison of waist circumference percentiles versus body mass index percentiles for diagnosis of obesity in a large cohort of children. International Journal of Peadiatric Obesity 2010 Apr;5(2):151-6.
26. Janssen I, Katzmarzyk PT, Ross R. Body mass index is inversely related to mortality in older people after adjustment for waist circumference. Journal of the American Geriatrics Society. 2005 Dec;53(12):2112-8.
27. Goran MI, Gower BA. Relation between visceral fat and disease risk in children and adolescents. American Journal of Clinical Nutrition. 1999 Jul;70(1):149S-56S.
28. Flodmark CE, Sveger T, Nilsson-Ehle P. Waist measurement correlates to a potentially atherogenic lipoprotein profile in obese 12-14-year-old children. Acta Paediatrica. 1994 Sep;83(9):941-5.
29. Freedman DS, Dietz WH, Srinivasan SR, Berenson GS. The relation of overweight to cardiovascular risk factors among children and adolescents: the Bogalusa Heart Study. Pediatrics. 1999 Jun;103(6 Pt 1):1175-82.
30. Cowin I, Emmett P. Cholesterol and triglyceride concentrations, birthweight and central obesity in pre-school children. ALSPAC Study Team. Avon Longitudinal Study of Pregnancy and Childhood. International Journal of Obeisty Relataed Metabolic Disorders,. 2000 Mar;24(3):330-9.
31. Rodriguez-Rodriguez E, Palmeros-Exsome C, Lopez-Sobaler AM, Ortega RM. Preliminary data on the association between waist circumference and insulin resistance in children without a previous diagnosis. European Journal of Pediatrics,. 2011 Jan;170(1):35-43.
32. Neovius MG, Linne YM, Barkeling BS, Rossner SO. Sensitivity and specificity of classification systems for fatness in adolescents. American Journal of Clinical Nutrition. 2004 Sep;80(3):597-603.
33. Falaschetti E, Hingorani AD, Jones A, Charakida M, Finer N, Whincup P, et al. Adiposity and cardiovascular risk factors in a large contemporary population of pre-pubertal children. European Heart Journal. 2010 Dec;31(24):3063-72.

Table 1. Mean (95% t - confidence intervals) anthropometric measurements at each measurement occasion

	Y7 (age 11-12)		Y9 (age 13-14)		Y11 (age 15 – 16)	
	Boy	Girl	Boy	Girl	Boy	girl
	n=330	n=347	n= 331	n=328	n=252	n=239
Stature (cm)	148.1 (147.4 to 148.9)	149.2 (148.4 to 150.0)	164.5 (163.6 to 165.4)	160.3 (159.6 to 160.9)	174.2 (173.3 to 175.1)	164.3 (163.2 to 165.3)
	n=317	n= 346	n=329	n=320	n=251	n=239
Mass (kg)	41.6 (40.5 to 42.6)	43.3 (42.3 to 44.4)	54.4 (53.2 to 55.7)	54.1 (52.8 to 55.4)	63.6 (62.2 to 65.1)	58.8 (57.3 to 60.3)
	n=317	n=346	n=329	n=320	n=251	n=239
BMI ($kg.m^2$)	18.8 (18.5 to 19.2)	19.3 (18.8 to 19.7)	20.0 (19.6 to 20.4)	20.9 (20.5 to 21.4)	20.9 (20.5 to 21.4)	21.7 (21.3 to 22.2)
sBMI	0.445 (0.315 to 0.575)	0.353 (0.227 to 0.479)	0.314 (0.189 to 0.438)	0.343 (0.208 to 0.478)	0.196 (0.0541 to 0.337)	0.256 (0.102 to 0.409)
	n=321	n=340	n=331	n=328	n=252	n=238
WC (cm)	67.5 (66.5 to 68.5)	65.7 (64.8 to 66.6)	73.5 (72.5 to 74.5)	74.4 (73.2 to 75.6)	79.0 (77.9 to 80.1)	78.2 (76.9 to 79.3)
sWC	0.792 (0.675 to 0.908)	0.843 (0.697 to 0.989)	0.818 (0.709 to 0.928)	1.52 (1.38 to 1.67)	0.943 (0.827 to 1.06)	1.89 (1.79 to 2.04)
	n=321	n=340	n=331	n=328	n=251	n=238
WHtR	0.456 (0.449 to 0.462)	0.440 (0.435 to 0.446)	0.447 (0.441 to 0.453)	0.464 (0.457 to 0.471)	0.453 (0.447 to 0.459)	0.476 (0.469 to 0.483)

Table 2. Coefficients (SE) from multilevel logistic models considering the prevalence of obesity over time (reference = boy)

		sBMI	sWC	WHtR
	Fixed part			
B_0	Reference (boy, year7[intercept])	-1.533(0.168)*	-1.864(0.158)*	-1.562(0.154)*
B_1	Gender (girl)	-0.195(0.237)	0.576(0.206)	-0.137(0.216)
B_2	Occasion (increment for boys)	-0.349(0.129)*	0.350(0.112)*	-0.166(0.120)
B_3	Gender_Occasion (increment for girls)	0.290(0.178)	0.603(0.148)*	0.629(0.160)*
	Random part			
	Variance (u_{0j})	3.074(0.337)*	1.257(0.185)*	1.690(0.231)*
	Units (pupils)	741	742	742
	Units (year)	1802	1810	1809

logit (obese) = $\beta_0 + \beta_1$ (girl) + β_2 (occassion) + β_3 (girl.equation)

B = the change in the outcome for a one unit change in the predictor (for logistic regression B equals the change in the logit of the outcome variable associated with one unit change in predictor variable); SE = standard error; * significant at $p < 0.05$

Table 3. Comparison of RADS centiles data to McCarthy et al (2001) data for measured WC (cm)

			centiles						
Age			5th	10th	25th	50th	75th	90th	95th
11-12 years	Boys	RADS	56.4	57.5	60.5	65.5	71.5	80.5	85.5
		McCarthy	51.9	53.6	56.6	60.2	64.1	67.9	70.4
	Girls	RADS	54.5	56.5	59.5	64.5	71.5	79.5	84.5
		McCarthy	52.0	53.2	55.4	58.2	61.1	65.4	68.1
13-14 years	Boys	RADS	60.7	63.5	66.5	72.0	77.5	84.5	91.9
		McCarthy	54.8	56.9	60.4	64.6	69.0	73.1	75.5
	Girls	RADS	60.2	62.5	65.5	72.0	81.0	91.0	99.1
		McCarthy	55.3	56.4	58.7	61.7	65.3	69.1	71.8
15-16 years	Boys	RADS	68.1	69.8	73.5	77.4	83.8	89.5	97.1
		McCarthy	59.0	61.1	64.8	69.3	74.2	79.0	82.0
	Girls	RADS	64.5	68.1	72.2	76.5	82.7	91.5	99.5
		McCarthy	57.6	58.9	61.3	64.4	67.9	71.7	74.3

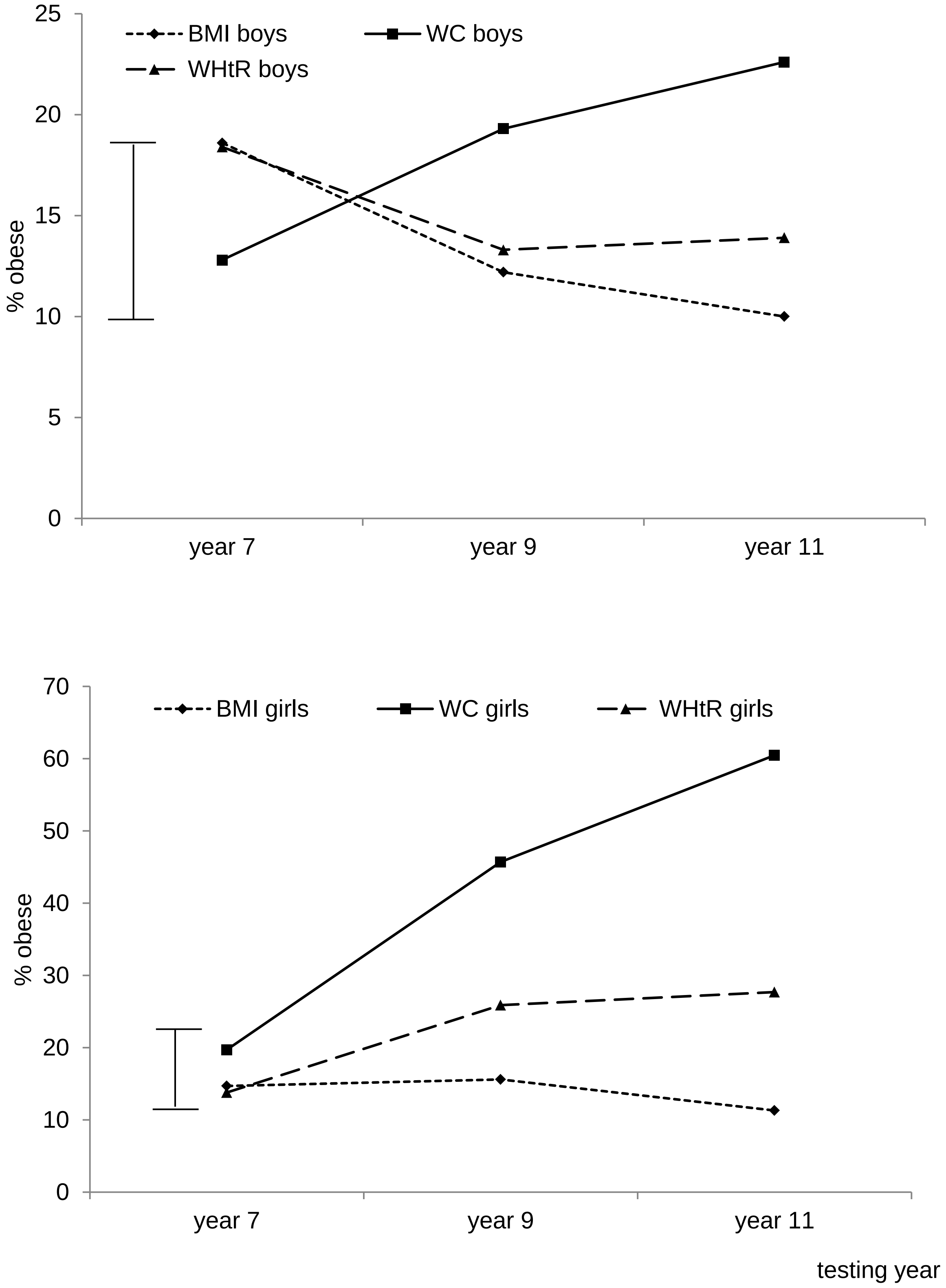

Figure 1. Prevalence of obesity measured by BMI, WC and WHtR over time in boys (top) and girls (bottom) [Black vertical lines represents approximate 95% confidence interval for the increase in prevalence over time]