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Evidence for central obesity risk-related thresholds for adolescents aged 11 to 18 years in England using the LMS method

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ABSTRACT

Introduction: Central obesity has been shown to better indicate health risks compared to general obesity. Measures of central obesity include waist-to-height ratio (WHtR), waist-to-hip ratio (WHR) and waist circumference (WC). The National Institute of Health and Care Excellence (NICE) recently recommended the use of WHtR alongside body mass index (BMI) to identify risks in adults and children, whilst recognising the need for more evidence relating to WHtR in children. This study explores risk thresholds for central obesity measures throughout adolescence. It compares these with those currently recommended in England and discusses whether these thresholds are age- and sex-specific.
Methods: Data on adolescents aged 11 to 18 years from the Health Survey for England (HSE) during 2005 to 2014 was used to calculate WHtR, WHR and WC percentiles. Next, smoothed lambda-mu-sigma (LMS) curves were created and the percentiles which align with the adult thresholds at age 18 years identified. This allows the most appropriate risk related thresholds for each measure during adolescence to be determined.
Results: WHtR LMS curves are stable and flat throughout adolescence. WHR decreases in girls and WC increases in both boys and girls, during adolescence. Across all measures, there is slightly more fluctuation in higher percentiles, and in girls' WHR.
Discussion: In practice, WHtR thresholds are simple to use to identify central obesity related risks. In particular, they are recommended because the same thresholds can be used for males and females and for adolescents and adults. The results support NICE guidance to use WHtR thresholds alongside BMI thresholds to identify individual risk.
Implications and contribution: This study uses central obesity measures, including waist-to-height and waist-to-hip ratios, to investigate risk-related thresholds for adolescents. It is the first to do so using English data. It provides support for current NICE recommendations to use adult waist-to-height thresholds in adults and children, alongside BMI measures in clinical and non-clinical settings.

Introduction

BMI is the most commonly used measure of obesity in both children and adults and is used worldwide. However, research is increasingly suggesting that measures of central obesity have a part to play in identifying risk. Measures of central obesity include waist-to-height ratio (WHtR), waist-to-hip ratio (WHR) and waist circumference (WC). Some studies have suggested that central obesity is a better indicator of health risks than general obesity [1–3] and that central obesity is more associated with health risks [4], including mortality [2], type 2 diabetes [5], hypertension [6] and cardiovascular disease [7] than Body Mass Index (BMI), a measure general obesity.

The National Institute of Health and Care Excellence (NICE) have recommended the use of WHtR and suggest the same risk thresholds of WHtR$\geq$ 0.5 (increased central adiposity) and WHtR$\geq$ 0.6 (high central adiposity) for adults with a BMI less than 35 including those with high muscle mass, as well as all children regardless of BMI [8]. However, they recognised that the evidence for WHtR thresholds in children was not as

Abbreviations: BIV, Biologically Implausible Value; BMI, body mass index; cm, centimeters; GAM, generalised additive models; HSE, Health Survey for England; IOTF, International Obesity Task Force; LMS, lambda-mu-sigma; NICE, National Institute for Health and Care Excellence; WC, waist circumference; WHO, World Health Organisation; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

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good as it was for adults. They therefore recommended further research on the accuracy of measurements for assessing health risks in children and young people [8].

There are established risk thresholds for WHtR, WHR and WC in adults, but these are less clear in children and adolescents. BMI risk thresholds have been used for some time in children; these age and sex-specific thresholds are determined using curves developed to align with BMI thresholds for adults at the age of 18 years [9,10]. Similar thresholds for central obesity measures have been explored for children and adolescents in other settings including the United States [11], Colombia [12], Poland [13], Greece [14], Germany [15] and Pakistan [16], but not using data from England.

Providing risk based thresholds for adolescents will allow epidemiologists to better explore central obesity across the lifecourse. It will also allow researchers to investigate the likelihood or prevalence of risk related obesity or overweight in adolescents, using measures other than BMI. In addition, it may allow better monitoring of childhood development and changes in adolescents growth.

This study's objective is to develop age- and sex-specific percentile curves for WHtR, WHR and WC throughout adolescence. This will allow risk-related thresholds to be determined for each measure, specific to adolescents in England.

Methods

Data

The Health Survey for England (HSE) [17] is a nationally representative cross-sectional annual survey monitoring population health in England. Information is collected annually from people living in private households. Around 10,000 (8000 adults and 2000 children) individuals take part in the survey each year. Participating households are randomly sampled each year. Data is collected by interview and, with participant consent, a nurses visit. In this study, data from 2005 to 2014 of the HSE were used to investigate central obesity measures in children between the ages of 11 and 18 years; this is because after 2014, age is no longer provided in years, only age groups. Missing data are assumed to be missing at random.

Written informed consent was obtained from participants, or their parents where appropriate [17]. The HSE was given a favourable outcome by the East Midlands – Nottingham 2 Research Ethics Committee (REC reference: 15/EM/0254).

Measures

Age and sex were reported by the participant and recorded by the interviewer. Age was measured in years and sex was recorded as male or female. Weight and height are measured by the interviewer [18]; weight (to the nearest 100 g) is recorded in kilograms (kg), and height (to the nearest millimetre) and recorded in centimetres (cm). Waist circumference (measured at the midpoint between the lower rib and the upper margin of the iliac crest) and hip circumference (measured at the widest point with tape measure parallel to the floor) are measured by a trained nurse for children 11 years and over [18,19] and recorded in centimetres (cm) to the nearest 0.1 cm (i.e. the nearest millimetre).

WHtR and WHR were calculated as follows:

$$WHtR = \frac{waist\ circumference(cm)}{height(cm)}$$

$$WHR = \frac{waist\ circumference(cm)}{hip\ circumference(cm)}$$

Statistical methods

A Box-Cox power transformation was used to standardise the data for each measure. Smooth percentile curves were created using the lambda-mu-sigma (LMS) method [20]. Cubic splines for each of the adiposity measures, with knots at each year of age were created using the Box-Cox power (L), the median (M) and the coefficient of variation (S). Outliers were excluded if they were more than 4 standard deviations from the mean because they were assumed to be biologically implausible values (BIVs), in accordance with previous literature [21].

Age- and sex-specific thresholds for each adiposity measure are created by linking the corresponding percentiles in childhood to the adult thresholds at the age of 18 years. This method is described in more detail by Cole and Lobstein [10], and is parallel to the childhood BMI thresholds used by the International Obesity Task Force (IOTF) [9].

Established adult thresholds

The established WHtR thresholds in adults are taken from recently updated NICE clinical guidance which states that a WHtR$\geq$ 0.5 indicates an increased central adiposity and WHtR$\geq$ 0.6 indicates high central adiposity in men, women and children [8]. The thresholds for WHR are taken from the World Health Organisation (WHO) definitions; a WHR $\geq$ 0.9 in men and $\geq$ 0.85 in women is considered to substantially increase the risk of metabolic complications [22]. The WHO thresholds were also used for WC; WC> 94 cm in men and > 80 cm in women is considered to increase the risk of metabolic complications and a WC> 102 cm in men and > 88 cm in women is considered to substantially increase the risk of metabolic complications.

Statistical analysis was carried out in Stata 18 [23].

Results

There were 11,139 observations for 11 to 18 year olds in the HSE between 2005 and 2014, inclusive. Table 1 shows the number of observations for which weight, height, WC, WHtR, hip circumference and WHR were collected, along with the number of observations after BIVs were removed. From the sample of 11,139, there were 6708 valid WHtR measures, 7095 valid WHR measures and 7084 valid WC measures.

Figs. S1-S3 in the supplementary material shows the distributions of the transformed data (after Box-Cox transformation) for WHtR, WHR and WC, respectively, by age and sex. The distributions approximate normality following the transformations, indicating that the models fit well and are able to predict accurately.

Table 2 shows the LMS parameters for WHtR by age and sex as well as the age- and sex-specific threshold values that correspond to the adult thresholds of 0.5 and 0.6. Fig. 1(a&b) shows that the smoothed LMS curves for WHtR are relatively flat in both boys and girls. The median is relatively stable around 0.45 in both boys and girls.

Table 3 shows the LMS parameters for WHR by age and sex as well as the age- and sex-specific threshold values that correspond to the adult threshold of 0.9 in men and 0.85 in women. Fig. 1(c&d) shows smoothed LMS percentile curves for WHR in boys and girls. Similar to WHtR, these curves were relatively flat, particularly in boys. Girls saw a slight decrease in median WHR with an uptick just before reaching 18 years, when it started to increase again. Boys had higher WHR on average than girls, assimilating with the higher thresholds in adults. This difference increased slightly with age.

Table 4 shows the LMS parameters for WC by age and sex as well as the age- and sex-specific threshold values which correspond to the adult threshold of 94 cm and 102 cm in men and 80 cm and 88 cm in women. Fig. 1(e&f) shows smoothed LMS percentile curves for WC in boys and girls. Unlike WHtR and WHR, median WC increased steadily with age in both boys and girls between the ages of 11 and 18 years, as well as the percentiles linked to high- and medium-risk WC. Boys had a higher median WC than girls, a difference that also increased with age.

Across all measures, there was slightly more fluctuation in higher percentiles and in girls' WHR.

Table 1
Starting sample and observations removed due to biologically implausible values (BIVs).

	Total participants	Weight	Height	Waist (WC)	WHtR	Hip	WHR
Starting sample	11,139	9547	9779	7113	6739	7112	7105
Sample after BIVs removed	-	9517	9779	7084	6708	7112	7095

Table 2
Age and sex specific Waist-to-Height-Ratio (WHtR) L, M and S parameters and thresholds aligned with 0.5 in boys and 0.6 in girls at 18 years.

	Boys					Girls				
				Thresholds					Thresholds	
Age	L	M	S	0.5	0.6	L	M	S	0.5	0.6
11	-2.3342	0.4611	0.1257	0.5032	0.5896	-2.1909	0.4467	0.12623	0.4819	0.5712
12	-2.9348	0.4512	0.1237	0.4929	0.5880	-1.9881	0.4506	0.12966	0.4869	0.5769
13	-3.3844	0.4485	0.1290	0.4931	0.6114	-2.1617	0.4430	0.12624	0.4779	0.5659
14	-2.9330	0.4439	0.1272	0.4862	0.5851	-2.5447	0.439	0.12865	0.4752	0.5736
15	-3.1924	0.4384	0.1291	0.4816	0.5904	-2.1832	0.4395	0.12399	0.4734	0.5586
16	-2.6838	0.4422	0.1240	0.4826	0.5705	-1.7581	0.4498	0.12590	0.4845	0.5664
17	-3.5539	0.4469	0.1283	0.4915	0.6152	-2.6473	0.4411	0.14509	0.4828	0.6112
18	-2.7453	0.4559	0.1296	0.5	0.6	-1.8277	0.4600	0.13980	0.5	0.6

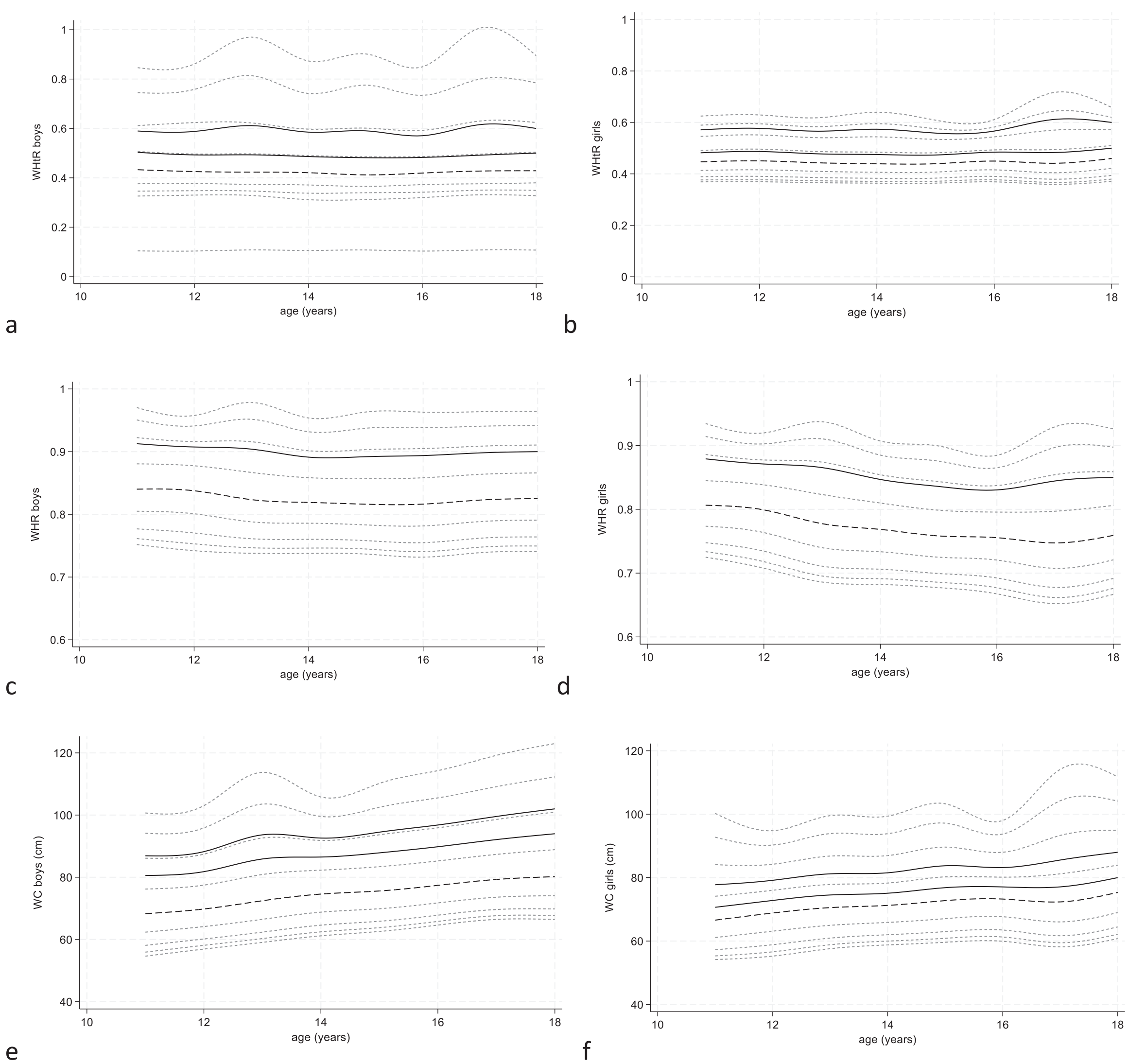

Fig. 1. Cubic splines fitting LMS curves for WHtR, WHR in boys and girls aged 11 to 18 years. LMS curves for the 3rd, 5th, 10th, 25th, 75th, 90th, 95th and 97th percentiles (dotted lines), median (dashed lines) and percentiles aligning with adult thresholds (solid lines). Adult thresholds are: 0.5 and 0.6 waist-to-height ratio (WHtR) in both boys (a) and girls (b); waist-to-hip ratio (WHR) 0.9 in boys (c) and WHR 0.85 in girls (d); waist circumference (WC) 94 cm and 102 cm in boys (e) and WC 80 cm and 88 cm in girls (f). L – skewness, M – Median, S – Coefficient of Variation.

Table 3
Age and sex specific Waist-to-Hip-Ratio (WHR) L, M and S parameters and thresholds aligned with 0.9 in boys and 0.85 in girls at 18 years.

	Boys				Girls			
				Threshold				Threshold
Age	L	M	S	0.9	L	M	S	0.85
11	-2.0407	0.84020	0.06633	0.91266	-2.5890	0.80642	0.06515	0.87915
12	-0.7804	0.83766	0.06758	0.90743	-1.1227	0.79913	0.06917	0.87107
13	-3.2701	0.82346	0.07008	0.90401	-2.6065	0.77753	0.07868	0.86543
14	-2.9632	0.81900	0.06514	0.89123	-2.3266	0.76858	0.07307	0.84683
15	-3.6529	0.81617	0.06609	0.89197	-2.9511	0.75829	0.07127	0.83586
16	-3.0512	0.81633	0.06899	0.89377	-1.7262	0.75557	0.07341	0.83045
17	-2.9407	0.82282	0.06721	0.89804	-2.7081	0.74737	0.08758	0.84449
18	-2.8165	0.82514	0.06712	0.9	-2.6257	0.75919	0.08231	0.85

Table 4
Age and sex specific Waist Circumference (WC) L, M and S parameters and thresholds aligned with 94 cm and 102 cm in boys and 80 cm and 88 cm in girls at 18 years.

	Boys					Girls				
				Thresholds					Thresholds	
Age	L	M	S	94 cm	102 cm	L	M	S	80 cm	88 cm
11	-1.8558	68.30	0.14706	80.584	86.915	-2.3071	66.60	0.14078	70.654	77.756
12	-2.2543	69.80	0.13780	81.809	88.241	-1.4042	68.85	0.13699	72.807	79.160
13	-2.5516	72.45	0.14250	85.886	93.650	-1.9822	70.55	0.13269	74.535	81.204
14	-2.1185	74.60	0.13126	86.508	92.605	-2.1433	71.25	0.12649	75.088	81.525
15	-2.5379	75.60	0.12896	87.853	94.508	-2.1179	72.75	0.13160	76.839	83.748
16	-2.8412	77.40	0.12529	89.818	96.808	-1.5361	73.25	0.12475	77.074	83.171
17	-3.0367	79.30	0.12430	92.119	99.556	-2.2911	72.35	0.15042	77.086	85.547
18	-2.8144	80.20	0.13221	94	102	-2.0608	75.35	0.14359	80	88

Discussion

This study calculated age- and sex-specific risk-related thresholds for WHtR, WHR and WC using smoothed curves created using the LMS method for adolescents in England. Although LMS tables are available for WC in children in the UK [24], these are over 20 years old and this is the first study that explores risk thresholds for WHtR, WHR and WC in adolescents in England. In addition, the study uses nationally representative data. The repeated cross-sectional data means that there is no attrition as there would be using cohort or panel data. Similarly, correlations between repeated data points for the same participants cannot bias the results. The results of this study are of interest to both epidemiologists interested in identifying population level risk and clinicians determining individual risk.

WHtR percentiles were found to be stable throughout adolescence, whereas WHR decreased in girls and WC increased in both boys and girls. The stable median and smoothed WHtR percentile curves showed a similar story to previous studies which used data from Pakistan [16], Colombia [12] and the United States [11]. However, these were in contrast to one Polish study [13] which produced curves that fluctuated much more during adolescence, as well as decreasing steeply in younger children. This emphasises the importance of having country-specific risk thresholds.

The flat curves found in this study for WHtR throughout adolescence, suggest that the adult risk thresholds could also be reasonable risk thresholds for future ill health in 11 to 18 year olds in England. The curves which correspond to WHtR at 0.5 and 0.6 at the age of 18 years, provide support for the current NICE clinical guidelines which suggest that these thresholds are suitable for adults (with BMI<35) and children alike [8]. The suggested WHtR thresholds also have the benefit of being the same for males and females and so in practice are easier to implement for both clinicians and individuals monitoring their own central adiposity.

WHR in girls showed a slight decline with age suggesting that the adult thresholds may be inappropriate in younger adolescents. This decline in WHR among girls could be due to changes in both hip and waist circumferences during puberty, particularly around the menarche, the time a girl has her first period [25]. Puberty accelerates growth (height) particularly in boys [26] and this could lead to fluctuations in the LMS curves and differences between boys and girls. WHR are also slightly complicated by the fact that they differ for males and females. Previous research has found WHR curves fluctuated more than this those in this study [13]. They used the same measurement cites as the Health Survey for England and so differences in measurement protocol do not explain these differences. Further research is needed to determine what could be causing these differences.

WC curves increased during adolescence, in both boys and girls. This is in line with previous literature using data from around the world [11–13,16], including in the United Kingdom [24], and particularly for boys [14,27]. This means that WC would be more complex to use in practice, as age- and sex-specific thresholds would be required, as is required for BMI thresholds in childhood. Previous literature has also shown that WHtR is a better predictor of health risk than combined measures of BMI and WC in adults [3] and this study suggests that the same may be true for adolescents.

The smoothed LMS curves fluctuate at different points and differently across different measures in girls and boys. This could be due to changes in body shape resulting from puberty. Differences between boys and girls could be impacted by differences in body changes during puberty and an earlier onset of puberty in girls than in boys [25]. Results from this study suggest that WHR and WC fluctuate more in girls than in boys. This could be due to increases in waist and hip circumference during puberty [25]. Future research into whether these fluctuations coincide with common changes in body shape could give more insight. Fluctuations are also greater in the higher percentile curves, which would suggest that any changes in body shape may affect adolescents living with obesity more than others.

This study was limited by the data. Waist measurements were only available for individuals of 11 years of age and over. Data needed is cross sectional so it is possible that waist measures for younger children could be collected relatively easily in the future. Sample size for this age group was fairly small for each year of data and so multiple years were combined in order to achieve an increased sample size. Data used was from 2005 to 2014, and more recent data may show some changes to the results; the prevalence of obesity remained relatively stable in England between 2014 and 2019 [28], but there is evidence that it increased in children and adolescents during the Covid-19 pandemic [29]. However, given the stable nature of WHtR throughout adolescence, results for WHtR would not be expected to substantially differ. More recent data was not used because the HSE only provides age group rather than age in years from 2015 onwards. It is possible that the relationship between age and adiposity measures change more subtly or dramatically between the intervals of years of age, however, due to the data being provided in whole years it is not possible to determine whether this is the case or not.

The LMS method was used in this study to aid comparisons with the majority of existing studies that use LMS with data from other countries. However, generalised additive models (GAMs) are a potential alternative method and could be explored in future research. They provide a flexible approach by allowing the data itself to determine the shape of the curve between the dependent and independent variable and can prevent overfitting.

This article does not directly test the risks related to measurement thresholds; rather, it extrapolates the already established risk-related thresholds used in adults, to adolescents. Further research could be conducted to determine the risks related to these thresholds in adolescents.

This study suggests that WHtR may be the most efficient and simple way of identifying health risks associated with central obesity in adolescents. WHtR percentile curves remain stable throughout adolescence, meaning that the already established adult thresholds can be used in 11 to 16 year olds. Similarly, given that thresholds are consistent for girls and boys, they are easier to implement and provide a clearer public health message. However, policy makers and clinicians should consider the views of people living with obesity or other medical conditions when the use of WHtR. Some individuals may feel that waist measures are more invasive than weight measures [30] and so BMI may still be appropriate in some cases. The advice given by NICE to using BMI to identify general obesity alongside WHtR to identify central obesity [8] provides a good balance.

A recent study [24] has suggested that WHtR overestimates the risk to shorter people, and that weight should instead be adjusted by height using the formula: $WC(height^{-0.5})$. Further research is needed to determine whether WHtR overestimates risk in shorter adolescents. Regardless, WHtR has the benefit that it is easier to calculate and understand, particularly for members of the public. For example, the NICE guidance [8] to "'keep the size of your waist to less than half of your height" (or WHTR < 0.5) provides a clear public health message. There is a trade off between measuring risk more precisely and conveying a simple and clear public health message.

In summary, this study provides age- and sex- specific thresholds for WHtR, WHR and WC in 11 to 17 year olds in England and gives evidence to support the use of adult risk thresholds for WHtR in adolescents. Results from this study will help support future epidemiological research which aims to study central obesity across the lifespan. The thresholds could also be used in clinical settings, assuming that the same measurement protocols are used, particularly when measuring waist and hip circumferences.

Ethical statement

The HSE was given a favourable outcome by the East Midlands – Nottingham 2 Research Ethics Committee (REC reference: 15/EM/0254).

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CRediT authorship contribution statement

Laura A. Gray: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of Competing Interest

The author declares no conflict of interests.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.orcp.2024.07.002.

References

[1] Lee CMY, Huxley RR, Wildman RP, Woodward M. Indices of abdominal obesity are better discriminators of cardiovascular risk factors than BMI: a meta-analysis. J Clin Epidemiol 2008;61(7):646–53. https://doi.org/10.1016/j.jclinepi.2007.08.012.

[2] Bosomworth NJ. Normal-weight central Obesity. Can Fam Physician 2019;65:399–408.

[3] Ashwell M, Gibson S. Waist-to-height ratio as an indicator of "early health risk": simpler and more predictive than using a "matrix" based on BMI and waist circumference Setting, participants and outcome measures: Recent data from 4 years. BMJ Open 2016;6:10159. https://doi.org/10.1136/bmjopen-2015.

[4] Hoefle G, Saely CH, Aczel S, et al. Impact of total and central obesity on vascular mortality in patients undergoing coronary angiography. Int J Obes 2005;29(7):785–91. https://doi.org/10.1038/sj.ijo.0802985.

[5] Kapoor N, Lotfaliany M, Sathish T, et al. Obesity indicators that best predict type 2 diabetes in an Indian population: Insights from the Kerala Diabetes Prevention Program. J Nutr Sci 2020;9:1–7. https://doi.org/10.1017/jns.2020.8.

[6] Zhang X, Yao S, Sun G, et al. Total and abdominal obesity among rural Chinese women and the association with hypertension. Nutrition 2012;28(1):46–52. https://doi.org/10.1016/j.nut.2011.02.004.

[7] Dobbelsteyn CJ, Joffres MR, MacLean DR, et al. A comparative evaluation of waist circumference, waist-to-hip ratio and body mass index as indicators of cardiovascular risk factors. The Canadian Heart Health Surveys. Int J Obes 2001;25(5):652–61. https://doi.org/10.1038/sj.ijo.0801582.

[8] NICE. NICE clinical guideline 189: obesity: identification, assessment and management (Updated 2023, Orginally Published 2014). London, UK; 2023.

[9] Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. Br Med J 2000;320(1240):1–6. https://doi.org/10.1136/bmj.320.7244.1240.

[10] Cole TJ, Lobstein T. Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. Pediatr Obes 2012;7(4):284–94. https://doi.org/10.1111/j.2047-6310.2012.00064.x.

[11] Sharma AK, Metzger DL, Daymont C, Hadjiyannakis S, Rodd CJ. LMS tables for waist-circumference and waist-height ratio Z-scores in children aged 5-19 y in NHANES III: association with cardio-metabolic risks. Pediatr Res 2015;78(6):723–9. https://doi.org/10.1038/pr.2015.160.

[12] Ramírez-Vélez R, Moreno-Jiménez J, Correa-Bautista JE, et al. Using LMS tables to determine waist circumference and waist-to-height ratios in Colombian children and adolescents: The FUPRECOL study. BMC Pediatr 2017;17(1):1–11. https://doi.org/10.1186/s12887-017-0919-4.

[13] Kułaga Z, Świąder-Leśniak A, Kotowska A, Litwin M. Population-based references for waist and hip circumferences, waist-to-hip and waist-to-height ratios for children and adolescents, and evaluation of their predictive ability. Eur J Pediatr 2023;182(7):3217–29. https://doi.org/10.1007/s00431-023-05001-4.

[14] Tambalis K, Panagiotakos D, Arnaoutis G, et al. Establishing cross-sectional curves for height, weight, body mass index and waist circumference for 4-to 18-year-old Greek children, using the Lambda Mu and Sigma (LMS) statistical method. Hippokratia 2015;19(3):239–48.

[15] Rönnecke E, Vogel M, Bussler S, et al. Age- and sex-related percentiles of skinfold thickness, waist and hip circumference, waist-to-hip ratio and waist-to-height ratio: results from a population-based pediatric cohort in Germany (LIFE Child). Obes Facts 2019;12(1):25–39. https://doi.org/10.1159/000494767.

[16] Asif M, Aslam M, Altaf S, Mustafa S. Developing waist circumference, waist-to-height ratio percentile curves for Pakistani children and adolescents aged 2-18 years using Lambda-Mu-Sigma (LMS) method. J Pediatr Endocrinol Metab 2020;33(8):983–93. https://doi.org/10.1515/jpem-2019-0527.

[17] NHS Digital. Health survey for England - health, social care and lifestyles. ⟨https://digital.nhs.uk/data-and-information/areas-of-interest/public-health/health-survey-for-england—health-social-care-and-lifestyles⟩. Published 2024. Accessed June 6, 2024.

[18] Hirani V. Adult Anthropometric measures, overweight and obesity; 2011. https://data.parliament.uk/DepositedPapers/Files/DEP2012-1861/132327-10.pdf.
[19] Boniface S, Bridges S, Craig R, et al. Health survey for England: volume 2 - methods and documentation; 2011. https://files.digital.nhs.uk/publicationimport/pub09xxx/pub09300/hse2011-methods-and-docs.pdf.
[20] Cole TJ, Green PJ. Smoothing reference centile curves: the lms method and penalized likelihood. Stat Med 1992;11(10):1305–19.
[21] Fry JM, Temple JB. Discrepancies in self-reported and measured anthropometric measurements and indices among older Australians: prevalence and correlates. BMC Public Health 2022;22(1):1–12. https://doi.org/10.1186/s12889-022-14326-y.
[22] WHO Expert Consultation. Waist circumference and waist-hip ratio report of a WHO expert consultation; 2008.
[23] StataCorp. Stata: Release 18; 2023.
[24] McCarthy HD, Jarrett KV, Crawley HF. The development of waist circumference percentiles in British children aged 5.0-16.9y. Eur J Clin Nutr 2001;55(10):902–7.
[25] Kirchengast S, Göstl A. Body composition characteristics during puberty in girls and boys from Eastern Austria. Int J Anthr 2006;21(1):45–54. https://doi.org/10.1007/s11599-006-9004-3.
[26] Soliman A, De Sanctis V, Elalaily R. Nutrition and pubertal development. Indian J Endocrinol Metab 2014;18:S39–47. https://doi.org/10.4103/2230-8210.145073.
[27] Lopez-Legarrea P, Garcia-Rubio J, Oviedo-Silva F, Collado-Mateo D, Merellano-Navarro E, Olivares PR. Waist circumference and waist:height ratio percentiles using LMS method in Chilean population. 183-139 Nutr Metab Cardiovasc Dis 2017;27. https://doi.org/10.1016/j.numecd.2016.09.010.
[28] Opazo Breton M, Opazo Breton Gray LA. An age-period-cohort approach to studying long-term trends in obesity and overweight in England (1992 - 2019). Obesity 2023;31:823–31.
[29] NHS England. National Child Measurement Programme, England 2020/21 School Year; 2021. ⟨https://digital.nhs.uk/data-and-information/publications/statistical/national-child-measurement-programme/2020-21-school-year#⟩.
[30] Dunkley AJ, Stone MA, Patel N, Davies MJ, Khunti Dunkley KA, Waist KK. Waist circumference measurement: knowledge, attitudes and barriers in patients and practitioners in a multi-ethnic population. Fam Pract 2009. https://doi.org/10.1093/fampra/cmp048.