Are we over-diagnosing obesity in pre-school children?

Charlotte Wright

School of Medicine, College of Medical, Veterinary & Life Sciences, University of Glasgow

Running title: Diagnosing obesity in pre-adolescent children

Corresponding author: Charlotte M. Wright, Royal Hospital for Children
Office Block CO/2, QE Hospital Campus, Govan, Glasgow G51 4TF charlotte.wright@glasgow.ac.uk

Competing interests: All authors have completed the Unified Competing Interest form available on request from the corresponding author and declare no support from any organisation for the submitted work

Funding sources: There was no specific funding for this analysis**.** The GMS cohort has been supported by a wide range of grants over time, notably: the Henry Smith Charity and Sport Aiding Research in Kids (SPARKS), the Gateshead NHS Trust R&D, Northern and Yorkshire NHS R&D, Northumberland, Tyne and Wear NHS Trust, the National Prevention Research Initiative (incorporating funding from British Heart Foundation; Cancer Research UK; Department of Health; Diabetes UK; Economic and Social Research Council; Food Standards Agency; Medical Research Council; Research and Development Office for the Northern Ireland Health and Social Services; Chief Scientist Office, Scottish Government Health Directorates; Welsh Assembly Government and World Cancer Research Fund), the Children's Foundation and the Scottish Government Health Directorates Chief Scientist Office.

Authorship; CW conceived, designed and drafted the manuscript and she is its guarantor. She also set up the GMS cohort and undertook additional analysis of their data for this article. She affirms that the manuscript is an honest, accurate, and transparent account.

WHAT IS THE PROBLEM?

Recent surveys have found almost a quarter of children at school entry to be overweight or obese, leading to suggestions that this is where preventive interventions should be focused. However, others dispute this, as tracking of body mass index (BMI) from preschool age is weak, with 63% of obese toddlers reverting to overweight or healthy weight at later ages[1], while BMI z scores relate weakly to adiposity in younger, compared to older overweight children[2].

This paper explores the possibility that this lack of persistence of early obesity may be the result of a classification artefact. This issue arose when an obese toddler, seen by a specialist, was reported to have improved, despite no change in their BMI. The explanation for this was evident on the BMI chart. This is illustrated with a fictitious example in figure 1, where a child's centile normalises over time, despite no reduction in BMI. We are used to the idea of children catching-down toward normality, as other children growth taller or heavier around them, as the whole growth curve rises over time. However, here the median BMI is the same at both ages. Can it be right, that extreme BMI centiles are crossed at so much lower levels in younger children than in mid childhood, when the average BMI is not increasing?

HOW IS OBESITY IN CHILDHOOD CURRENTLY DEFINED?

We still have no properly validated upper threshold for unhealthy BMI in childhood. The upper thresholds for healthy adult BMI were established using their association with adverse health outcomes and mortality[3], but it was (and is still) not possible to do this in childhood. This is because we lack the large-scale, long-term data required, as until recently overweight in childhood was rare, while most adverse adult health outcomes do not occur till middle age or beyond. Therefore, the upper centiles on BMI charts were first introduced simply "*to identify children who were unusually fat or thin*"[4] . However, using a fixed centile as an upper threshold, then defined the same proportion of children at all ages as being at risk of obesity.

As time has gone on, the arbitrary nature of those thresholds has been forgotten, and they are now generally considered to represent actual overweight and obesity. We currently have no way of determining the true prevalence of obesity at different ages, but it seems unlikely that the prevalence overweight and obesity would actually be constant across childhood, as few new-born infants are overweight, yet two thirds of adults are overweight. When these centile thresholds are applied to contemporary BMI data[5] (Figure 2) the proportion with overweight and obesity is much higher than when the thresholds were set, reflecting the marked overall increase in obesity over time, but the proportions are still broadly similar at all ages, though rather higher in the teens.

WHAT DO THE BMI CENTILES CURVES TELL US?

Median BMI is largely constant up to the age of 9 and rises gently thereafter (figure 1). In contrast, the upper limit of 'normal' BMI increases more steeply with age, giving the BMI chart a distinctive wedge shape. An interpretation of this is that obesity is actually still relatively rare in the first few years, so that the range of BMI is narrow. Then, as increasing numbers of obese-prone individual children become overweight and then obese, the upper limit increases, reflecting an increasing proportion of children with unhealthy BMIs. Meanwhile, the median continues to reflect the BMI of mainly non obese individuals. This upper limit also seems to increase more steeply with age in populations with higher rates of obesity. The UK 1990 (UK90) reference[4] used data collected early in the UK obesity epidemic in the 1970s and 80s, the WHO 2007 reference used US data collected before 1977[6], while the US CDC reference includes data collected up to 1994[7]. The median curves for all three charts are very similar at most ages and there is little difference between the +2 SD lines before age 5. However, by age 12 the recent CDC +2 SD line is 3.5 kg/m^2 higher than both UK90 and WHO, and by age 15-19 years the WHO is more than 1 kg/m^2 higher than the UK90. This variability has also been described in the datasets used to construct the

International Obesity Task Force (IOTF) cut-offs, where the coefficient of variation, a measure of the width of the distribution, rose sharply for all datasets in the first few years, but differed substantially between countries in their slope.[8]

AN ALTERNATIVE APPROACH TO ASSESSING BMI?

Given that the median BMI is much less variable, both over age and between populations, we should consider whether the percent above (or below) median BMI (%median) would be a useful alternative. This approach, which has been used widely for growth monitoring in the past, adjusts for the change in the average value with age, but not for any change in the amount of variability. If, 30 years ago, those defining childhood obesity had opted for %median instead of BMI centiles, what effect would that have on the prevalence of obesity at different ages now? There are no standard thresholds for %median BMI, but an adult BMI of 25 kg/m^2 is roughly 20% above and BMI 30 kg/m^2 roughly 40% the median at ages 18-20 years. It could be argued that it is not appropriate to apply adult obesity thresholds to children, but in the absence of any directly validated thresholds, an explicit link to validated adult levels seems sensible; this is analogous to the approach used to set the IOTF centile-based thresholds. Using these thresholds in the same cohort[5] (Figure 2) gives a very different picture, with very low rates of overweight and obesity in the youngest children, rising progressively to similar proportions as for the centile thresholds in the teens.

The % median approach has its own limitations, as it assumes that, in health, there is no increase in variability of BMI with age, in contrast to centile based thresholds, which assume that all the increase in variability with age (at the time the data were collected) represented healthy normality. It seems likely that as children go into their teens there may be more variability in BMI, reflecting changes in in lean mass, but it also seems highly likely that progressively more individuals become unhealthily obese as they progress into their teens. We have no gold standard measure of childhood obesity, but the true prevalence must

lie somewhere between these two estimates. Further work is needed, ideally to explore the extent to which these different approaches predict worse adult health, but this is only possible if suitable data can be found. In the meantime, an exploration of how reliably each detects children who are over-fat would be helpful.

CONCLUSIONS

Centile charts are vital tools in child health, but when applied to BMI it is likely that they greatly inflate the prevalence of pre-school obesity, with the risk that attention is deflected from older children who are at higher risk. We must also recognise the inherent danger of defining healthy limits for teenagers, based on upper BMI thresholds which rise as the obesity epidemic increases. Further attention needs to be given to defining how the true prevalence of obesity varies with age, but it seems likely that more stringent thresholds are required for younger children.

ACKNOWLEDGEMENTS

I am grateful to Jill Morrison for first pointing out the clinical implication of this anomaly and to Jonathan Wells and Tim Cole and for many discussions about how to investigate it and for Tim's helpful comments on an earlier draft this manuscript, as well as those of three anonymous reviewers.

I am grateful to all those involved with The Gateshead Millennium Study: we are indebted to the families and children who took part, to Ashley Adamson who now leads the GMS cohort, to Kathryn Parkinson for her help in setting the cohort up and her work on it over the years, to John Reilly and Ann Le Couteur who led relevant survey waves and to Angela Jones and Laura Basterfield for their comments on drafts, as well as the External Reference Group, Gateshead Health NHS Foundation Trust, Gateshead Education Authority and local schools.

References

1. Pan L, May AL, Wethington H, et al. Incidence of Obesity Among Young US Children Living in Low-Income Families, 2008-2011. *Pediatrics* 2013;132(6):1006-13. doi: peds.2013-2145 [pii];10.1542/peds.2013-2145 [doi]
2. Vanderwall C, Randall Clark R, Eickhoff J, et al. BMI is a poor predictor of adiposity in young overweight and obese children. *BMC pediatrics* 2017;17(1):135. doi: 10.1186/s12887-017-0891-z
3. Flegal KM, Graubard BI, Williamson DF, et al. Excess deaths associated with underweight, overweight, and obesity. *Jama* 2005;293(15):1861-67. doi: 10.1001/jama.293.15.1861
4. Cole TJ, Freeman JV, Preece MA. Body mass index reference curves for the UK, 1990. *ArchDisChild* 1995;73(1):25-29.
5. Parkinson KN, Pearce MS, Dale A, et al. Cohort profile: the Gateshead Millennium Study. *IntJEpidemiol* 2011;40(2):308-17. doi: dyq015 [pii];10.1093/ije/dyq015 [doi]
6. De Onis M, Onyango AW, Borghi E, et al. Development of a WHO growth reference for school-aged children and adolescents. *BullWorld Health Organ* 2007;85(9):660-67. doi: S0042-96862007000900010 [pii]
7. Kuczmarski RJ, Ogden CL, Grummer-Strawn LM, et al. CDC growth charts: United States. *Advance data* 2000(314):1-27.
8. Cole TJ, Lobstein T. Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. *Pediatric obesity* 2012;7(4):284-94. doi: 10.1111/j.2047-6310.2012.00064.x

LEGEND TO FIGURES

Figure 1: A boy aged 3 with a BMI = 20, is close to the 99.6th centile (severe obesity). If he remains the same BMI till age 9 years, by then he is within the normal range. Over the same period, the median BMI has not risen and BMI is 25% above the median at both ages.

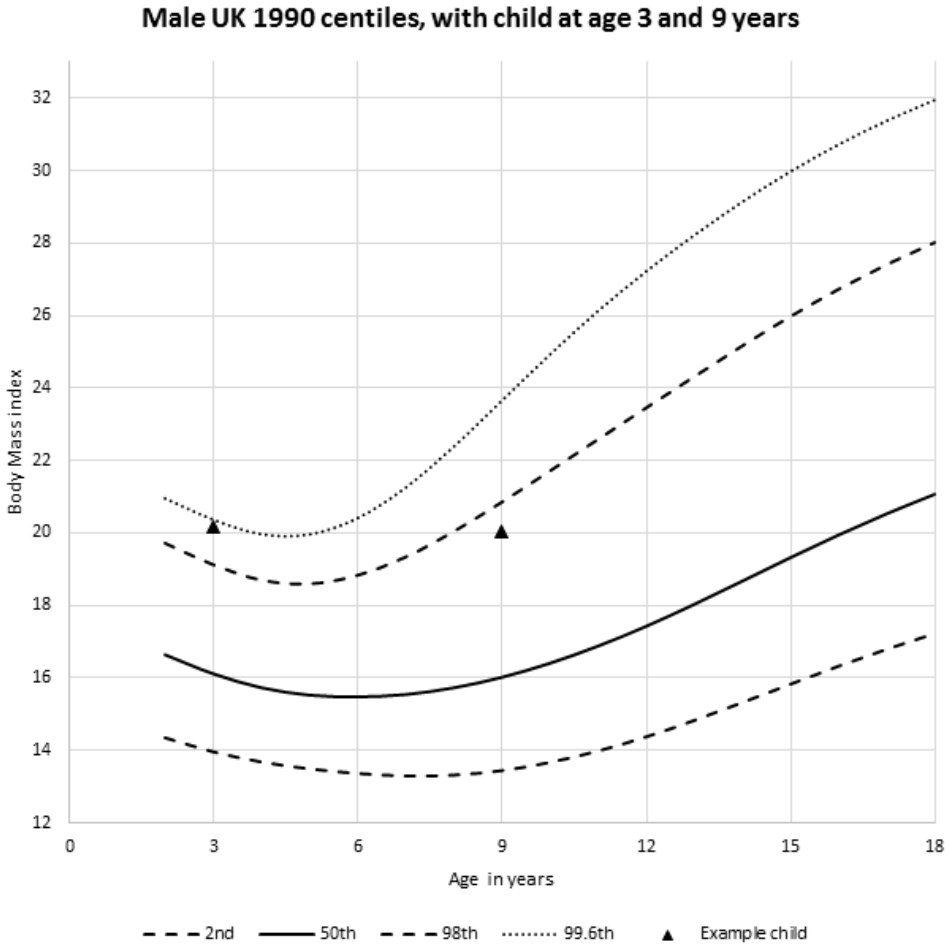

Figure 2: Proportion of children in Gateshead Millennium Study (GMS) cohort above BMI z score and %median thresholds by age and sex.

The GMS cohort are a population-representative cohort of 1029 infants born in recruiting weeks in Gateshead, UK in one year (1999-2000) and followed up to young adulthood, with the most recent data used in the current analysis collected in 2016[5].