Body mass index has risen more steeply in tall than in short three year olds: serial cross-sectional surveys 1988-2003

Iain E Buchan[1], Peter E Bundred[2], Denise J Kitchiner[3], Tim J Cole[4]

1. NIBHI, Medical School, The University of Manchester
2. Department of Primary Care, The University of Liverpool
3. Royal Liverpool Children's Hospital
4. Centre for Paediatric Epidemiology and Biostatistics, Institute of Child Health, University College London

Correspondence to:

Iain E Buchan
NIBHI
Medical School
The University of Manchester
Oxford Road
Manchester M13 9PT
+44 (0)161 275 5160
buchan@manchester.ac.uk

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Abstract

Objective To monitor the changing relationship between BMI and height in young children.

Design Annual cross-sectional surveys using health-visitor-collected routine data 1988-2003.

Setting Wirral, England.

Participants 50,455 children (49% female) each measured once at the age of 3 years.

Main outcome measures Weight, height and derived body mass index (BMI = weight/height^2) adjusted for age and sex (British 1990 revised reference) using standard deviation scores (SDS).

Results From 1988 to 2003 mean BMI increased by 0.7 kg/m^2 while mean height fell by 0.5 cm. Over the same period the weight-height correlation rose from 0.59 to 0.71 ($P < 0.0001$) due to BMI increasing faster in the taller than the shorter children. Among the shortest 10% of children mean BMI rose by 0.12 (95% confidence interval -0.05 to 0.28) kg/m^2 as against 1.38 (1.19 to 1.56) kg/m^2 among the tallest 10%, a twelve-fold difference. Adjustment for age, sex, seasonality, birth-weight and deprivation did not alter the findings.

Conclusions Among 3-year-old children in Wirral, where BMI has been rising for 16 years, the largest increase in BMI has occurred in the tallest children while in the shortest BMI has hardly changed. Tall stature has therefore become important for child obesity. It suggests a drive to increasing adiposity in young children that involves both growth and appetite, with faster-growing and hungrier children now more exposed to the ‘obesogenic’ environment.

Introduction

Child obesity is a major and increasing public health problem in many countries, with the prevalence in the UK rising rapidly in children as young as three years.[1] Being fat as a child causes immediate harm, such as low self-esteem, and has consequences for adult health including an increased risk of type 2 diabetes and cardiovascular disease.[2] The factors leading to obesity are well-known – a positive energy balance arising from dietary energy intake exceeding expenditure.[3] This principle is the basis for strategies to tackle population obesity, with a focus on encouraging physical activity and healthy eating.[4,5]

Childhood obesity differs from adult obesity in that children grow, and child obesity is now emerging as a *growing* problem – in both senses of the word. Obese children tend to be taller than their lean counterparts,[6,7] tall stature in childhood is a risk factor for adult obesity,[8] and in particular, rapid early infant weight gain predicts obesity later in childhood.[9-11] Ong et al. showed that infants who gained weight rapidly in their first 2 years were both fatter and taller at 5 years than their slower-growing counterparts.[10] Stettler et al. showed a similar effect after just four months of early rapid weight gain.[12] As Ong et al. put it, “acceleration of growth postnatally … overshoots the genetic trajectory”. Singhal & Lucas[11] recently propounded a “growth acceleration hypothesis” that early rapid weight gain is an important risk factor for several chronic diseases including obesity. Their hypothesis includes Barker’s foetal origins hypothesis[13] as a special case.[14]

Height at any age in childhood is a marker of skeletal growth up to that point. Body mass index (BMI = weight/height^2) is conventionally used to measure child obesity,[15-18] and in preschool children BMI is effectively uncorrelated with height.[19-22] However in older children, particularly during puberty, there is a strong positive correlation between BMI and height.[19-21] This means that preschool, mean BMI is similar in tall and short children, whereas in puberty it is appreciably higher in taller children. This pattern in turn means that between preschool and puberty, BMI increases faster in tall children than short, which reflects the greater body fat of tall children.[23]

Despite the dramatic increase in child obesity since the 1980's, the BMI-height relationship in children of the same age is assumed not to have changed over time, i.e. in preschool children the correlation has remained near zero. This is important because if the correlation had changed, it would indicate that there had been a relative change in BMI in tall children compared to short. The aim here is to revisit routine health data on 3-year-old Wirral children,[1] a socially and ethnically stable population, to test whether the BMI-height correlation changed over the period 1988 to 2003.

Methods

Routine data collected by health visitors in Wirral, England at the preschool (3-year) review were obtained for the 16-year period 1988-2003, including sex, dates of birth and measurements of height and weight. Of the 51,492 records examined, 692 (1.3%) were excluded due to missing data, while a further 345 (0.7%) were excluded as weight or height was more than 5 standard deviations (SD) from the mean. This left 50,455 children of whom 47,851 (94.8%) had a matching birth-weight.

Birth-weight for gestation, weight, height and body mass index were converted to standard deviation (SD) scores (SDS) adjusted for age and sex using the British 1990 revised growth reference.[16,24,25] The SDS expresses the measurement relative to British children in 1990 in units of standard deviations above or below the median, and is useful to detect trends in both mean and variability. Applied to the reference population the mean SDS is zero and the SD is one. The prevalence of overweight (including obesity) and obesity was defined using the International Obesity Taskforce (IOTF) BMI cut-offs.[18]

Mean, SD and Pearson correlation was calculated for each measurement by year of measurement. The relationship between BMI, height and time was investigated in three ways: a) the log-log regression of weight on height, where the height regression coefficient is the optimal power p in the Benn index weight/height^p; b) the linear regression of BMI on height for each year separately, and then for all years combined including a height by year interaction; c) the linear regression of BMI on year for each tenth of the height SDS distribution separately. Adjustments were included for month of measurement, birth-weight and deprivation. Deprivation was assigned by area using the child's home postcode linked at Low Level Super Output Area to the Income Deprivation Affecting Children index[26] in the 45,300 records (90%) where it was recorded. Birth-weight was adjusted for sex and gestation via SDS. Both birth-weight and deprivation were both available in 43,193 records (86%). Interactions of sex with the other covariates were also tested for.

Main results are presented as effect (95% confidence interval).

Results

Complete anthropometric data at 3 years were available for 50,455 children (49.2% female), with mean age 3.1 (SD 0.2, range 2.6 to 4.5) years. Table 1 summarises height, weight and BMI by year, both as measurement and SDS, showing that height fell slightly with time, whereas weight and BMI rose steeply. The prevalence of overweight / obesity also rose over the period, from 12.2% / 2.2% in 1988 to 19.1% / 4.0% in 2003.

The mean annual increase in BMI adjusted for height, month of measurement and deprivation was 0.036 (0.034 to 0.039) SD per year, or 0.034 (0.032 to 0.037) SD per year when further adjusted for birth-weight (both $P < 0.0001$). So on average, 3-year-old children of the same height and birth-weight, from areas of comparable deprivation, were 15 x 0.034 = 0.51 SD fatter in mid-2003 than in mid-1988, an increase of 0.67 (0.62 to 0.72) kg/m^2. This corresponds to crossing upwards four-fifths of a centile channel on the British 1990 BMI chart (where the centiles are spaced two-thirds of an SD apart[27]).

Height, similarly adjusted, fell over the same period by 0.009 (0.006 to 0.011) SD per year, corresponding to a height reduction of 0.5 (0.4 to 0.6) cm over 15 years. The reduction occurred in the affluent as well as the poor areas. The SDs for height SDS and weight SDS were 1.08 and 1.06 overall, slightly greater than the expected value of 1, but they showed no obvious trend over time. For BMI SDS by contrast the SD fell from 1.24 to 1.04 over the 15 years, a striking fall in variability. Figure 1 shows the explanation for this – the correlation of BMI with height increased substantially from -0.1 in 1988 to 0.1 in 2003. For comparison the weight-height correlation increased from 0.59 to 0.71 over the same period.

Table 2 gives the regression coefficients of log weight on log height, both overall and by year, including adjustments for age and sex. Overall the coefficient (Benn index) is very close to 2, showing that the index weight/height^2 is almost perfectly uncorrelated with height. But the time trend tells a different story – in 1988 the optimal power was around 1.8, but by 2003 it had increased to around 2.2, a highly significant secular trend ($P < 0.0001$). This shows that at the start of the period BMI was slightly greater in short children compared to tall, but by the end the reverse was true. So over the 15-year period BMI had increased more in the tall children than the short. There was a significant sex interaction with log height, such that the optimal power for girls was 0.05 higher than for boys.

Figure 2 shows the mean increase in BMI over the study period for children in each tenth of the height distribution (all years combined), estimated from the regression of BMI on year, adjusted for age, sex, deprivation, month of measurement and birth-weight within each height group. It demonstrates a near-linear increase in BMI with height from the shortest to the tallest, independently of birth-weight and deprivation. For the shortest 10% of children (< 11th British height centile) the mean increase in BMI from 1988 to 2003 was 0.12 (-0.05 to 0.28) kg/m^2, while for the tallest 10% (> 93^{rd} British centile) the increase was 1.38 (1.19 to 1.56) kg/m², twelve times greater. These correspond to British 1990 BMI centile chart crossings upwards of a sixth of a channel for the shortest children and 1.6 channels for the tallest children respectively.

Figure 3 shows the complex dependence of IOTF overweight prevalence on height and time, with height divided into five groups from the shortest to the tallest. Overweight prevalence was essentially constant over time among the shortest children, but rose steeply among the tallest. During 1988-1991 the lowest prevalence was in the fourth fifth of height (98 cm, 0.7 SDS), while by 1999-2003 it had fallen to the second fifth (94 cm, -0.5 SDS). The J-shaped relationship between BMI and height is consistent with other studies.[7]

Birth-weight correlated weakly though highly significantly with 3-year weight (r = 0.29 [0.28 to 0.30]), height (r = 0.25 [0.24 to 0.26]) and BMI (r = 0.16 [0.15 to 0.17]). The correlation between birth-weight and BMI did not change over time (birth-weight by year interaction P = 0.5), even after adjustment for age, sex and month of measurement, so birth-weight did not explain the BMI trend. In analyses including height and birth-weight, height alone was a slightly stronger predictor of BMI than height adjusted for birth-weight.

Discussion

The results show that the increase in obesity between 1988 and 2003 among 3-year-old English children was disproportionately greater in taller children. In short children BMI increased only slightly over the 16-year period, whereas in tall children the increase was twelve times greater. At the start of the period the correlation between BMI and height was negative, with mean BMI slightly greater in short children than tall, but by the end the correlation had become positive, with tall children having the higher mean BMI. This same secular trend in the BMI-height relationship was seen in the regression of BMI on height and the Benn index weight/height^p.

There was also a counter-intuitive fall in the standard deviation of BMI, arising from the increasing weight-height correlation explaining progressively more of the variability in BMI.

The strength, consistency and linearity of the changing relationship suggests that tall stature has over time become important for obesity in this age group, the effect being largest in the tallest children and smallest in the shortest.

Study strengths and limitations

Our study design involves serial cross-sectional surveys over a long period of time, each with a large sample from a narrow age range, in an area with low migration and relatively little change in socio-economic status.[28] This design is appropriate for detecting secular trends in child populations, such as those we report, provided sampling bias is unsubstantial or controlled for. The fall in numbers of children we observed over time (see Table 1) was real and not due to sampling changes – a very similar fall was seen in birth numbers. There was a slight (6 week) increase in mean age at examination across the years – this was controlled for by using SDS, and there were no residual age influences in regression models. This provides some reassurance that the secular trend in the BMI-height relationship is genuine. A potential weakness of the study is the use of routinely collected data, which are not subject to formal quality control and so may be of poorer quality. The data have however been carefully cleaned, with obvious outliers excluded, and the standard deviations of weight SDS and height SDS are only slightly above unity. This is a sensitive indicator of data quality, as the standard deviation is unity by definition for the reference population, and any extra measurement error would tend to inflate it. In addition, biased or noisy data would attenuate any secular trend, implying that the underlying trend is actually stronger than shown.

Interpretation

What might explain the increase in BMI being concentrated among the taller children? The simplest explanation is that their lifestyle has changed over time, causing them to become progressively fatter through reduced activity and/or increased energy intake. There is little doubt that this lifestyle change has occurred,[29-31] but the problem is that *all* children are exposed to risk, not just the tall. The little evidence published on height-environment interaction suggests that tall children, particularly boys, tend to be more physically active, not less, than their short counterparts.[32] The lack of a sex difference in our findings also tends to rule out activity as an explanation, as girls are less active than boys.[33]

Research into the origins of child obesity is currently focused on foetal growth and birth weight,[34] and early postnatal growth,[35] where rapid growth is associated with later obesity. Among several possible mechanisms for this association, appetite control is receiving specific attention.[36,37] Ong et al[10] show that infants who grow fast early on are fatter later, and they view intrauterine constraint of foetal growth as the driving force for rapid postnatal weight gain via prenatal up-regulation of appetite,[38] with the excess growth starting immediately after birth and the rapid growers ending up taller than average as well as fatter.[10] Stunkard et al.[39,40] show that weight at 1 and 2 years is determined by energy intake rather than energy expenditure, and that appetite (as measured by nutritive sucking behaviour at 3 months) is an important factor affecting intake.

Appetite relates both to dietary intake and to growth, so it may explain the link between growth and increasing obesity.[41] Height at any age reflects accumulated growth since conception, so that at 3 years tall children have been growing faster than short children. Faster growth goes with a larger appetite in general, so taller children are likely to have (had) larger appetites. This faster growth may also be associated with increased maturation, as accelerated growth is associated with early menarche.[42] In boys, Sandhu et al[43] show that higher BMI just before puberty is associated with earlier puberty and higher BMI in late adulthood.

However there is an anomaly in our findings – a secular increase in appetite should have led to more growth and taller, heavier children, yet this has not happened. Over the 16 years studied, mean height fell by 0.5 cm despite the steep rise in weight. Whatever caused weight to rise did not simultaneously increase height. The stability of the underlying population makes this hard to explain in terms of changing ethnicity or socio-economic status.

Public health implications

The findings are important for public health. Interventions to prevent child obesity currently target diet and physical activity, on the assumption that energy imbalance is the problem. But if appetite has been up-regulated via programming, as the link between obesity and growth implies, the appropriate strategy would be to reduce appetite in the fastest growing infants. In practice this would be extremely difficult to do, particularly if appetite were programmed prenatally. Research is required to identify safe and effective early preventive interventions, possibly via changes to infant-feeding practices and/or pharmaceuticals.[44]

In conclusion, the association between height and weight at 3 years has increased over time because BMI has increased much more in tall than in short children. This suggests that much of the drive to increasing fatness arises from postnatal growth, probably mediated via appetite. Further research into the determinants of child adiposity and public health interventions to reduce high adiposity should prioritise studies early in life.

Contributors

IEB noted an exceptional height effect in Wirral health visitor data, did part of the analysis and led the writing of the paper. PEB provided the data, sought ethical approval, fed-back interim results to the Wirral health visitors and generated hypotheses. DJK worked on the manuscript and developed ideas with IEB and PEB. TJC directed the investigation towards overgrowth as a potential cause of child obesity, did part of the analysis and wrote the initial drafts of the paper with IEB. All authors saw and commented on the final version of the paper. IEB is guarantor of the paper.

Ethics

The Wirral Local Research Ethics Committee granted ethical approval for this study.

Conflict of interest statement

We declare that we have no conflict of interest.

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Table 1: Trends in height, weight and body mass index (BMI) in Wirral 3-year-olds between 1988 and 2003. Data are annual means (age-sex standardised), and means and SDs of standard deviation scores (SDS) based on the British 1990 growth reference.

		Height		**Weight**		**BMI**	
Year	**N**	**cm**	**SDS (SD)**	**kg**	**SDS (SD)**	**kg/m^2**	**SDS (SD)**
1988	3460	96.37	0.12 (1.09)	14.69	0.01 (1.07)	15.80	-0.13 (1.24)
1989	3344	96.69	0.21 (1.10)	14.77	0.05 (1.06)	15.78	-0.15 (1.24)
1990	3449	96.48	0.15 (1.12)	14.86	0.11 (1.05)	15.96	-0.01 (1.17)
1991	3603	96.61	0.18 (1.08)	14.87	0.11 (1.04)	15.93	-0.03 (1.18)
1992	3468	96.46	0.14 (1.07)	14.87	0.11 (1.01)	15.97	0.00 (1.16)
1993	3544	96.71	0.21 (1.08)	14.88	0.11 (1.05)	15.90	-0.05 (1.17)
1994	3676	96.66	0.20 (1.08)	14.98	0.17 (1.04)	16.02	0.04 (1.16)
1995	3312	96.58	0.18 (1.09)	14.97	0.17 (1.07)	16.04	0.05 (1.19)
1996	3255	96.21	0.08 (1.08)	14.97	0.17 (1.07)	16.17	0.16 (1.11)
1997	3046	96.11	0.05 (1.04)	15.04	0.21 (1.05)	16.28	0.24 (1.11)
1998	2993	96.28	0.10 (1.07)	15.17	0.28 (1.06)	16.37	0.30 (1.10)
1999	2865	96.23	0.08 (1.07)	15.13	0.26 (1.09)	16.35	0.29 (1.10)
2000	2609	96.15	0.06 (1.06)	15.09	0.24 (1.06)	16.33	0.28 (1.05)
2001	2741	96.10	0.05 (1.04)	15.16	0.27 (1.06)	16.41	0.34 (1.06)
2002	2687	96.06	0.04 (1.08)	15.21	0.31 (1.07)	16.49	0.40 (1.04)
2003	2403	96.03	0.03 (1.06)	15.14	0.26 (1.10)	16.42	0.34 (1.09)
All	**50455**	**96.38**	**0.12 (1.08)**	**14.97**	**0.17 (1.06)**	**16.11**	**0.11 (1.16)**

Table 2: Trends in Benn index for Wirral 3-year-olds between 1988 and 2003. Data are the regression coefficients of log weight on log height, both overall and by year, including adjustments for age and sex.

Year	**Benn index (95% CI)**
1988	1.76 (1.68 to 1.84)
1989	1.75 (1.67 to 1.83)
1990	1.84 (1.76 to 1.91)
1991	1.83 (1.76 to 1.91)
1992	1.78 (1.70 to 1.85)
1993	1.92 (1.84 to 1.99)
1994	1.80 (1.73 to 1.87)
1995	1.88 (1.80 to 1.96)
1996	2.05 (1.97 to 2.13)
1997	2.05 (1.97 to 2.13)
1998	2.04 (1.96 to 2.12)
1999	2.17 (2.09 to 2.26)
2000	2.12 (2.04 to 2.20)
2001	2.20 (2.11 to 2.28)
2002	2.18 (2.10 to 2.26)
2003	2.23 (2.14 to 2.32)
All	**1.95 (1.93 to 1.97)**

Figure 1: Increasing correlation between BMI and height among Wirral 3-year-olds from 1988 to 2003, plotted as annual Pearson correlations of standard deviation scores (based on the 1990 British growth reference) with bars showing 95% confidence intervals.

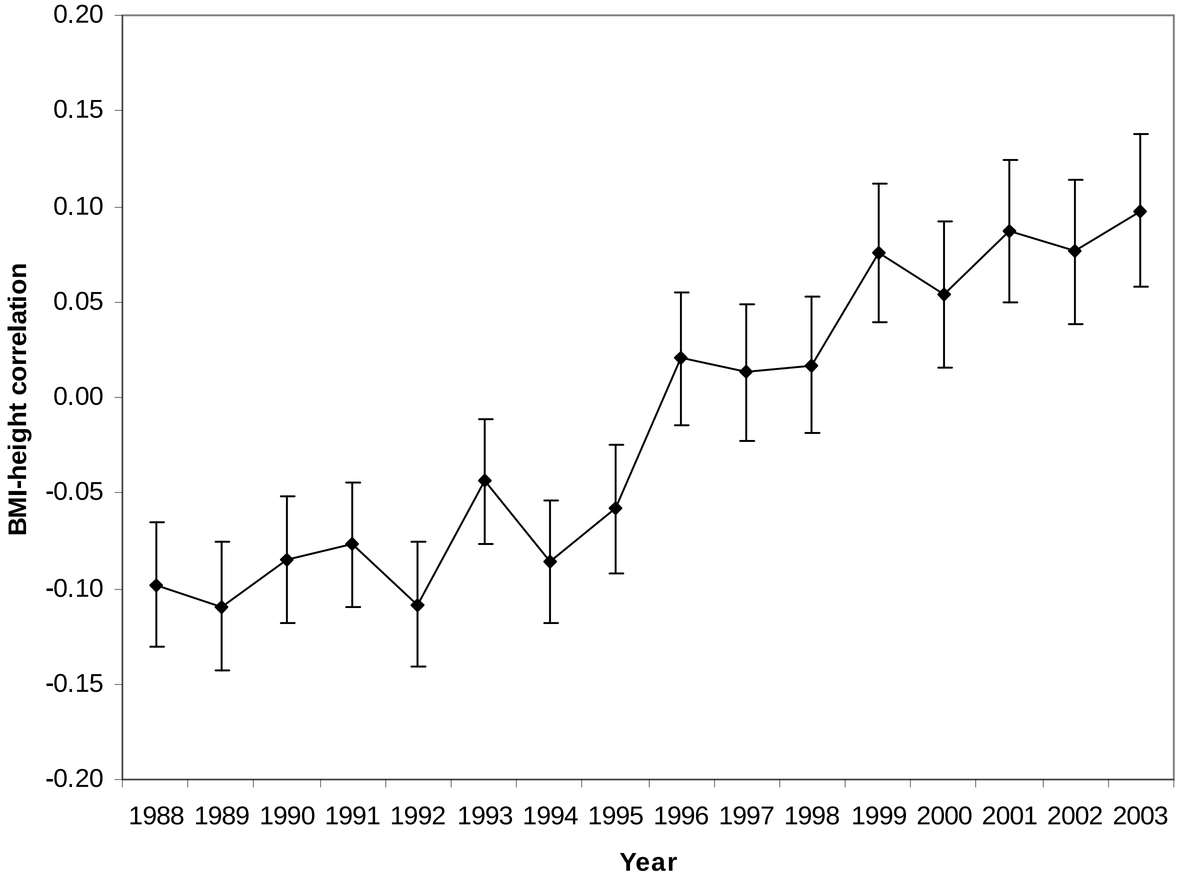

Figure 2: Increases in body mass index (BMI) in Wirral 3-year-olds from 1988 to 2003, by tenths of height, adjusted for age, sex, month of measurement, deprivation and birth-weight. Error bars represent 95% confidence intervals. The increase in BMI was twelve times greater for the tallest 10% than the shortest 10% of children.

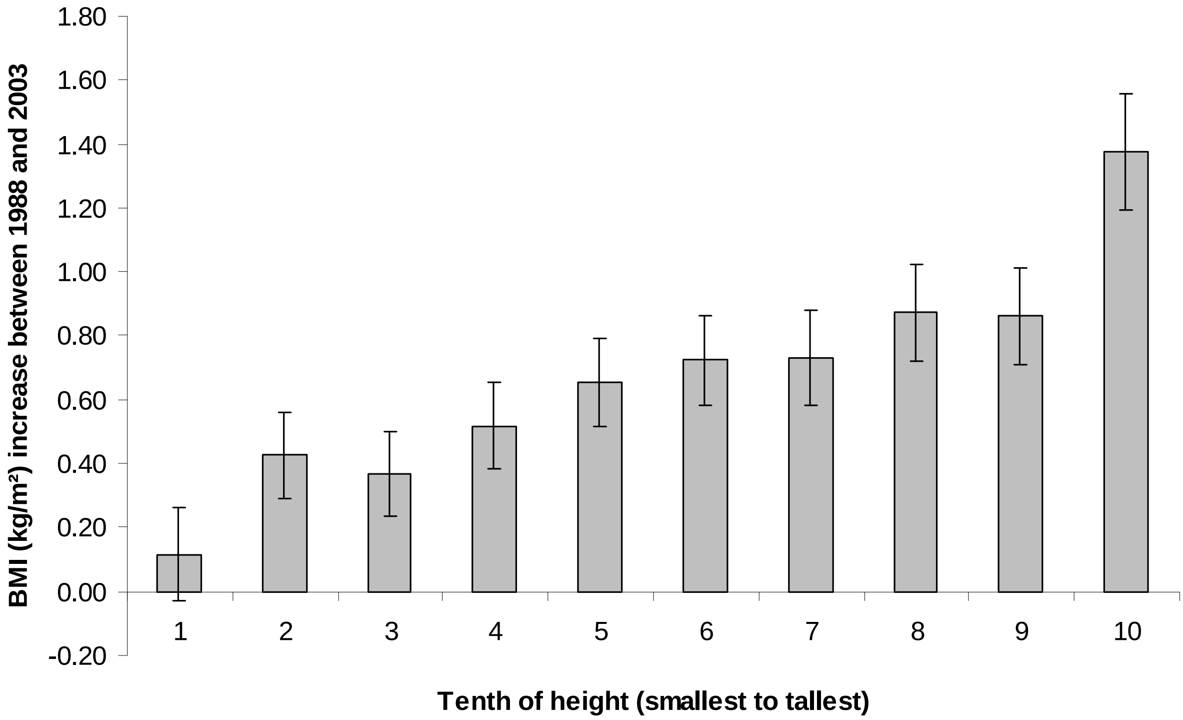

Figure 3: Trends over time in the prevalence (%) of overweight (IOTF) by fifths of the height distribution among Wirral 3-year-olds from 1988 to 2003. The prevalence is essentially constant among the shortest children, but rises more and more steeply with increasing height.