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PAPER

# Birth weight, childhood growth and abdominal obesity in adult life

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**OBJECTIVE:** To examine the relationship of adult abdominal obesity to birth weight, childhood growth and lifetime socioeconomic circumstances.
**METHODS:** A cohort of 3200 men and women with measured waist and hip circumference, height and weight at age 43 who have been followed since their birth in March 1946 in England, Scotland and Wales. Regression models were used to examine mean waist–hip ratio and waist circumference in relation to prospective measures of birth weight, weight relative to height in childhood at ages 4, 7, 11 and 15 and adult body mass index, and to test the independent and interactive nature of the associations and adjust for childhood and adult social class.
**RESULTS:** There was a small inverse effect of birth weight on waist–hip ratio ($P=0.037$) but not waist circumference in women, after adjustment for current body size. Relative weight at age 7 was inversely related to waist–hip ratio and waist circumference in men ($P<0.001$ for both) and waist circumference in women ($P=0.007$) after adjustment for current body size. These relationships were attenuated in men of large body mass index ($P<0.01$ for interactions between relative weight at 7 y and body mass index in both cases) but were not modified by birth weight. Relative weights at other ages showed similar patterns to those observed at age 7, the effect being weakest at age 4. These findings were independent of lifetime socioeconomic circumstances.
**CONCLUSION:** This study found a small prenatal inverse effect of fetal growth on adult waist–hip ratio due to a reduced hip size. There was also an inverse postnatal effect of childhood growth such that for any given adult body size those who had been lighter in childhood were more at risk of abdominal obesity. These relationships were independent of childhood socioeconomic circumstances and support the idea that insulin resistance may be linked to low weight in childhood.
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**Keywords:** birth weight; childhood weight; abdominal obesity; waist–hip ratio; waist circumference; birth cohort study

## Introduction

There is considerable evidence that impaired fetal growth raises the risk of diabetes and cardiovascular disease later in life and insulin resistance has been postulated as one of the mechanisms underlying these relationships.[1] Central obesity is strongly associated with insulin resistance, diabetes and cardiovascular disease,[2] and thus its relationship to fetal growth has received attention. Most[3–10] but not all[11–14] studies have found an inverse association between birth weight (or famine exposure during early gestation) and various measures of abdominal obesity in childhood or adult life. In all but one study,[6] this relationship was dependent on adjusting for current body size. In this case, a prenatal hypothesis has to be weighed against a postnatal hypothesis.[15] Measures of growth in childhood are needed to identify the most influential period of growth but none of the studies to date have such information. These studies have also generally not taken into account child and adult social circumstances which are known to be associated with body size,[16–20] and abdominal obesity in particular.[21]

We examined the relationship between birth weight and abdominal obesity at 43 y in a large national cohort with prospective information on birth weight, childhood growth, adult body shape, and lifetime socioeconomic circumstances.

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## Subjects and methods

The Medical Research Council's National Survey of Health and Development is a socially stratified sample of 2547 females and 2815 males followed up since their birth in England, Scotland and Wales in the first week of March 1946.[22] At the home visit at 43 y 1634 men and 1632 women (61% of the original cohort) were interviewed at home by research nurses. Loss to follow-up was due to death (7%), migration (11%), refusal (16%) and failure to trace (5%). The population interviewed was still representative in most respects of the cohort born in England, Scotland and Wales.[23] The nurses measured waist (cm) and hip circumference (cm) according to a standardised protocol in 1604 men and 1603 women. The study member was asked to stand straight with feet together, arms hanging loosely by their sides and looking straight ahead. To measure waist circumference, a measuring tape was applied at a point between the costal margin and the iliac crest and in line with the mid axilla. To measure hip circumference, the nurse located the greater trochanter, which is the widest part of the hips, at the level of the buttock line. In each case, the tape was pulled taut and a measurement to the nearest 1 mm was taken in mid-expiration. Waist–hip ratio was expressed as a percentage in the following analyses.

Information on birth weight, to the nearest quarter of a pound, was extracted from the birth records within a few weeks of delivery and converted into kilograms. Relative weight (weight expressed as a percentage of standard weight for age, height and sex in this general population sample[24]) was derived from measures of height and weight at 4, 7, 11 and 15 y. Relative weight at age 7 y was selected *a priori* as the marker of pre-pubertal growth. Body mass index (BMI; weight/height$^2$) was derived from height and weight measurements at 43 y, using standardised procedures described previously.[16]

Father's social class was used as a marker of socioeconomic circumstances in childhood, distinguishing between those who came from manual rather than non manual origins. Where there was no father in the household or his occupation was unknown ($n=160$) household overcrowding (two or more persons to a room) was used to identify those who came from poorer circumstances than others. Adult social class, based on the current or most recent occupation of the survey member or their partner (whoever had the higher social class) at 43 y, was taken as a marker of adult socioeconomic circumstances.

### Statistical analyses

The relationships between waist–hip ratio at age 43 and birth weight, relative weight at age 7 and adult BMI were tested using linear regression. In these models birth weight, childhood relative weight and BMI were entered as continuous variables. In order that any interaction between BMI and birth weight (or childhood relative weight) may be easily interpreted, the tests were carried out by grouping BMI into fifths and assessing whether the linear effect of birth weight (or relative weight) varied systematically across BMI categories. Systematic variation in the linear effect of childhood relative weight across birth weight categories was investigated in a similar manner. A final model tested whether the observed associations were independent of childhood and adult socioeconomic circumstances.

Waist–hip ratio depends on skeletal proportions and a high waist–hip ratio in those that are small at birth could be the result of small pelvic diameter rather than abdominal obesity.[7,25] Waist circumference may be a better marker of intra-abdominal obesity than waist–hip ratio.[26] These models were thus then repeated using first continuous measures of waist circumference and then of hip circumference at 43 y as the outcome.

Since the variation of waist–hip ratio was larger for women than for men and the effect of weight at different stages of life on waist–hip ratio may be different, these analyses were undertaken separately for men and women. A sex-standardised waist–hip ratio measure was used in further analyses to test whether the effects were significantly different for men and women (interactions of risk factors by sex). The results of such tests are reported where relevant.

Of the 1604 men and 1603 women with measured waist and hip measurements at 43 y, 1589 (99.1%) men and 1585 (98.9%) women also had their heights and weights measured at this age, and their birth weights and childhood and adult social class were known. Characteristics of this sample are provided in Table 1. Relative weight at 7 y was known for 1314 (81.9%) men and 1318 (82.2%) women. The mean birth weights and adult social class of those with and without this extra data did not differ. Women (but not men) from non-manual backgrounds were less likely ($P=0.021$) to have been weighed at age 7 (80.2%) compared with those from manual backgrounds (84.6%).

**Table 1** Characteristics of 1589 men and 1585 women in the 1946 birth cohort

| | n | *Males (%)* | *Females (%)* |
|---|---|---|---|
| Manual class in childhood | 3174 | 56.2 | 57.3 |
| Manual class in adult life | 3174 | 19.0 | 18.0 |
| *Measures at age 43* | | *Mean (s.d.)* | *Mean (s.d.)* |
| Waist–hip ratio (%) | 3174 | 91.3 (5.9) | 77.3 (6.3) |
| Waist circumference (cm) | 3174 | 91.9 (9.8) | 77.7 (11.1) |
| Hip circumference (cm) | 3174 | 100.6 (7.1) | 100.5 (10.1) |
| Weight (kg) | 3174 | 78.1 (12.1) | 65.7 (12.8) |
| Height (cm) | 3174 | 175.3 (65.4) | 162.3 (59.8) |
| BMI (kg/m$^2$) | 3174 | 25.4 (3.5) | 24.9 (4.7) |
| *Measures at age 7* | | | |
| Weight (kg) | 2644 | 23.0 (2.9) | 22.5 (3.2) |
| Height (cm) | 2738 | 120.3 (5.5) | 119.6 (5.6) |
| *Measures at birth* | | | |
| Weight (kg) | 3174 | 3.5 (0.5) | 3.3 (0.5) |

## Results

### Men

In the sample of 1589 men with complete information on birth weight, BMI and social class, birth weight was not related to adult waist–hip ratio but a slight negative trend emerged after adjustment for current body size (Table 2) due to the fact that birth weight was positively associated with BMI. BMI was strongly and positively related to waist–hip ratio ($P<0.001$). There was evidence of an interaction between birth weight and current body size for men whereby the negative effect of birth weight was stronger at lower levels of BMI ($P=0.049$).

In a sample restricted to 1314 men who also had valid measures of relative weight at 7 y, the mean waist–hip ratio increased as relative weight at 7 y increased but, after adjustment for BMI, waist–hip ratio was found to decrease with increasing relative weight ($P<0.001$; Table 3). As for the analysis with birth weight, there was a positive interaction ($P=0.003$) between BMI and childhood relative weight such that the inverse relationship between childhood relative weight and waist–hip ratio was attenuated in those of larger body mass. The decrease in waist–hip ratio was estimated to be 1.3% per 10% increase in relative weight in the lowest quintile of BMI compared with only 0.1% in the highest quintile. These findings remained after adjustment for birth weight, after including a birth weight by BMI interaction (which itself was attenuated and no longer significant), and after including a birth weight by relative weight interaction which was not significant.

In contrast to the findings for waist–hip ratio, birth weight was positively associated with waist and hip circumference, before and after adjustment for BMI (Table 2). Relative weight at 7 y was also strongly positively associated with waist and hip circumference before adjustment for BMI (Table 3). After adjustment for BMI, relative weight at 7 y became strongly inversely related to waist circumference reflecting the same pattern (including the interaction between relative weight at 7 y and BMI) observed for waist–hip ratio. Its association with hip circumference was also reversed but to a lesser extent.

For both childhood and adult measures of socioeconomic status, men from manual social classes had a higher mean waist–hip ratio and waist circumference compared with those from non-manual social classes (Table 4, unadjusted regression coefficients). Social class did not attenuate the relationship between the growth factors and adult waist–hip ratio or waist circumference (Table 4, adjusted model). Birth weight remained significantly and positively associated with

**Table 2** Waist–hip ratio, waist circumference and hip circumference in relation to birth weight in 1589 men and 1585 women, before and after adjustment for adult BMI

| | *Men* | | | | *Women* | | | |
|---|---|---|---|---|---|---|---|---|
| | *Unadjusted* | | *Adjusted for BMI* | | *Unadjusted* | | *Adjusted for BMI* | |
| | *Regression coefficient (95% CI)* | P-value | *Regression coefficient (95% CI)* | P-value | *Regression coefficient (95% CI)* | P-value | *Regression coefficient (95% CI)* | P-value |
| *Waist–hip ratio* | | | | | | | | |
| Birth weight (kg) | −0.03 (−0.59, 0.53) | 0.913 | −0.37 (−0.83, 0.09) | 0.115 | −0.37 (−1.02, 0.27) | 0.252 | −0.63 (−1.22, −0.04) | 0.037 |
| *Waist circumference* | | | | | | | | |
| Birth weight (kg) | 1.47 (0.54, 2.41) | 0.002 | 0.64 (0.16, 1.12) | 0.009 | 0.65 (−0.48, 1.78) | 0.261 | −0.32 (−0.91, 0.28) | 0.295 |
| *Hip circumference* | | | | | | | | |
| Birth weight (kg) | 1.64 (0.97, 2.31) | <0.001 | 1.11 (0.67, 1.54) | <0.001 | 1.30 (0.27, 2.32) | 0.013 | 0.41 (−0.10, 0.93) | 0.118 |

**Table 3** Waist–hip ratio, waist circumference and hip circumference in relation to relative weight at age 7 in 1314 men and 1318 women, before and after adjustment for adult BMI

| | *Men* | | | | *Women* | | | |
|---|---|---|---|---|---|---|---|---|
| | *Unadjusted* | | *Adjusted for BMI* | | *Unadjusted* | | *Adjusted for BMI* | |
| | *Regression coefficient (95% CI)* | P-value | *Regression coefficient (95% CI)* | P-value | *Regression coefficient (95% CI)* | P-value | *Regression coefficient (95% CI)* | P-value |
| *Waist–hip ratio* | | | | | | | | |
| Relative weight (10%) | 0.40 (0.00, 0.80) | 0.045 | −0.86 (−1.20, −0.54) | <0.001 | 0.71 (0.37, 1.05) | <0.001 | −0.15 (−0.48, 0.18) | 0.371 |
| *Waist circumference* | | | | | | | | |
| Relative weight (10%) | 2.09 (1.45, 2.73) | <0.001 | −0.96 (−1.30, −0.62) | <0.001 | 2.77 (2.18, 3.37) | <0.001 | −0.47 (−0.81, −0.13) | 0.007 |
| *Hip circumference* | | | | | | | | |
| Relative weight (10%) | 1.79 (1.33, 2.24) | <0.001 | −0.11 (−0.42, 0.21) | 0.503 | 2.53 (2.00, 3.07) | <0.001 | −0.42 (−0.71, −0.12) | 0.006 |

**Table 4** Waist–hip ratio and waist circumference in relation to body size and social circumstances in childhood and adult life in 1314 men

| | *Waist–hip ratio* | | | | *Waist circumference* | | | |
|---|---|---|---|---|---|---|---|---|
| | *Unadjusted regression coefficient (95% CI)* | *P-value* | *Adjusted[a] regression coefficient (95% CI)* | *P-value* | *Unadjusted regression coefficient (95% CI)* | *P-value* | *Adjusted[a] regression coefficient (95% CI)* | *P-value* |
| Birth weight (kg) | − 0.01 ( − 0.63, 0.60) | 0.961 | − 0.07 ( − 0.57, 0.44) | 0.780 | 1.50 (0.47, 2.53) | 0.004 | 1.00 (0.48, 1.52) | < 0.001 |
| Relative weight at 7 y (10%) | 0.40 (0.00, 0.80) | 0.045 | n/a | | 2.09 (1.45, 2.73) | < 0.001 | n/a | |
| Relative weight at 7 y (10%) | n/a | | | < 0.001 | n/a | | | < 0.001 |
| Bottom fifth BMI | | | − 1.32 ( − 2.15, − 0.50) | | | | − 2.03 ( − 2.89, − 1.17) | |
| 2nd fifth | | | − 1.68 ( − 2.41, − 0.95) | | | | − 1.27 ( − 2.03, − 0.51) | |
| 3rd fifth | | | − 0.74 ( − 1.46, − 0.01) | | | | − 1.38 ( − 2.13, − 0.63) | |
| 4th fifth | | | − 0.84 ( − 1.55, − 0.12) | | | | − 1.08 ( − 1.83, − 0.34) | |
| Top fifth | | | 0.00 ( − 0.62, 0.62) | | | | − 0.15 ( − 0.80, 0.50) | |
| Adult BMI (kg/m$^2$) | 0.98 (0.90, 1.05) | < 0.001 | 1.00 (0.92, 1.08)[b] | < 0.001 | 2.43 (2.35, 2.51) | < 0.001 | 2.50 (2.41, 2.58)[b] | < 0.001 |
| Manual–non-manual childhood social class | 1.80 (1.16, 2.44) | < 0.001 | 0.56 (0.02, 1.10) | 0.050 | 2.14 (1.07, 3.22) | < 0.001 | 0.84 (0.13, 1.54) | 0.020 |
| Manual–non-manual adult social class | 1.78 (0.97, 2.59) | < 0.001 | 1.17 (0.50, 1.86) | < 0.001 | 1.64 (0.27, 3.00) | < 0.001 | − 0.64 ( − 1.20, − 0.08) | 0.024 |

[a]Estimates from model containing all variables listed in table.
[b]Estimated effect of BMI for mean relative weight at 7 y.

waist circumference after adjustment for later body size and social class (Table 4, adjusted model for waist circumference)

Relative weights at 4, 11 and 15 y showed generally similar patterns with waist–hip ratio and waist circumference to those observed at 7 y. For waist–hip ratio, the inverse effect after adjusting for BMI was slightly weaker at ages 11 and 15 y, and weakest at age 4 y. For waist circumference the adjusted effect was of a similar magnitude at age 15 y, slightly weaker at age 11 y and not apparent at age 4 y.

## Women

In the sample of 1585 women with complete information on birth weight, BMI and social class, there was a slight negative association between birth weight and adult waist–hip ratio which became stronger and significant after adjustment for current body size (Table 2). The estimated effect was stronger in women than in men although this difference between the sexes was found not to be significant at the 5% level. BMI was strongly and positively related to waist–hip ratio ($P<0.001$) but there was no evidence of an interaction between birth weight and current body size ($P=0.272$).

In a sample restricted to 1318 women who also had valid measures of relative weight at 7 y, the mean waist–hip ratio increased as relative weight at 7 y increased ($P<0.001$; Table 3, unadjusted model). The positive relationship between childhood relative weight at 7 y and waist–hip ratio became inverse but non significant after adjusting for current body size and there was no evidence of an interaction between relative weight and BMI (Table 3, adjusted model). The effects of childhood relative weight on waist–hip ratio were significantly different at the 5% level from the effects observed in men and were not altered after adjustment for birth weight. There was no association between childhood relative weight at any other childhood ages and waist–hip ratio.

In contrast to the findings for waist–hip ratio, birth weight (unadjusted for current body size) was positively associated with waist and hip circumference (Table 2). Both effects were attenuated after adjustment for adult BMI and the relationship between birth weight and waist circumference became negative but non significant (Table 2). There was a larger negative association between relative weight at 7 y and waist or hip circumference than between relative weight and waist–hip ratio after adjusting for BMI (Table 3). This suggests that the change in relative weight between age 7 and adulthood had a similar effect on both waist and hip size. The effect of relative weight at 7 y on waist circumference reflected the same pattern as that observed for birth weight both before and after adjustment, but the effect of relative weight on hip circumference was opposite to the effect of birth weight after adjustment for BMI.

As for men, women from manual social classes had higher mean waist–hip ratios compared with those from non-manual social classes (Table 5, unadjusted models) but social class did not attenuate the relationship between the

**Table 5** Waist–hip ratio and waist circumference in relation to body size and social circumstances in childhood and adult life in 1318 women

| | *Waist–hip ratio* | | | | *Waist circumference* | | | |
|---|---|---|---|---|---|---|---|---|
| | *Unadjusted regression coefficient (95% CI)* | *P-value* | *Adjusted[a] regression coefficient (95% CI)* | *P-value* | *Unadjusted regression coefficient (95% CI)* | *P-value* | *Adjusted[a] regression coefficient (95% CI)* | *P-value* |
| Birth weight (kg) | −0.28 (−0.98, 0.42) | 0.436 | −0.46 (−1.10, 0.19) | 0.165 | 0.77 (−0.48, 2.03) | 0.228 | −0.06 (−0.73, 0.60) | 0.846 |
| Relative weight at 7 y (10%) | 0.71 (0.37, 1.05) | <0.001 | −0.13 (−0.46, 0.20) | 0.435 | 2.77 (2.17, 3.37) | <0.001 | −0.47 (−0.82, −0.13) | 0.007 |
| Adult BMI (kg/m$^2$) | 0.53 (0.46, 0.59) | <0.001 | 0.50 (0.43, 0.57) | <0.001 | 1.99 (1.93, 2.06) | <0.001 | 2.00 (1.93, 2.07) | <0.001 |
| Manual–non-manual childhood social class | 3.26 (2.41, 4.11) | <0.001 | 0.63 (−0.01, 1.27) | 0.056 | 3.57 (2.35, 4.78) | <0.001 | 0.35 (−0.31, 1.02) | 0.299 |
| Manual–non-manual adult social class | 1.72 (1.05, 2.40) | <0.001 | 1.80 (0.97, 2.62) | <0.001 | 6.44 (4.92, 7.97) | <0.001 | 1.30 (0.45, 2.16) | 0.003 |

[a]Estimates from model containing all variables listed in table.

growth factors and adult waist–hip ratio (Table 5, adjusted models). The effect size of birth weight on waist–hip ratio was reduced but this was due to a decreased unadjusted effect in the restricted sample rather than any attenuation due to relative weight or social class. In the fully adjusted model (Table 5) relative weight at 7 y was more strongly inversely related to waist circumference than to waist–hip ratio.

Relative weights at 4, 11 and 15 y generally showed similar patterns with waist–hip ratio and waist circumference to those observed at 7 y. As for our results for men, the relationship with waist circumference was weakest and non significant at age 4 y.

## Discussion

In a large national British cohort born immediately after the Second World War we found small direct inverse effects of weight at birth and in childhood on adult abdominal obesity, after adjusting for current body size and independent of social circumstances. Adjusting the effects of early life for later BMI attempts to separate out the effects of lean tissue, skeletal size and peripheral fat from those of central adiposity. BMI is an indicator of general fatness, muscularity and frame size but not visceral adiposity, whereas waist–hip ratio is a better indicator of visceral adiposity.[27] However, BMI is not a perfect marker and hence the adjustment is only approximate.

Some[3,4,7] but not all[5,11,14] previous studies that have examined the relationship between birth weight and waist–hip ratio have found a small inverse association after adjustment for current body size. Law *et al*[3] interpreted this association as evidence of a link between fetal growth and abdominal fatness. Alternatively Byberg *et al*[7] have suggested the association reflects a link between birth weight and hip circumference rather than abdominal obesity, as waist circumference was not related to birth weight. Similarly, the weaker relationship between birth weight and waist circumference in our study suggests that women of low birth weight are more likely to have a relatively small pelvis rather than be at greater risk of abdominal obesity. Further, the relationship between birth weight and adult waist–hip ratio in women was suggestive of a prenatal effect as this relationship was not modified by weight in childhood and was negative in direction before adjustment for BMI. The smaller but non significant inverse effect of birth weight on waist–hip ratio in men is also an effect of small hip size. Research findings remain inconsistent as other studies have found a stronger relationship of birth weight[5] or exposure to the Dutch famine in early gestation[10] on waist circumference than waist–hip ratio. There was no difference in waist–hip ratio in those exposed during gestation or as infants during the Leningrad siege,[13] but no information was available on waist circumference.

Other researchers have used subscapular to triceps skinfold (measured in adolescence or adult life) and have found an association with birth weight in some populations[6–9] but not others.[12] Truncal fat and waist–hip ratio may represent two different hormonal and metabolic states and it has been suggested that the former could be related to glucocorticoid sensitivity and programmed in early life.[7,28] Unfortunately this study did not measure subscapular or triceps skinfolds.

One of the advantages of this study over previous studies is its information on weight in childhood as well as at birth. We observed a positive overall relationship between relative weight at age 7 and adult waist–hip ratio in men and women which became negative on adjustment for BMI. Similar effects were observed for waist circumference alone. The stronger impact of childhood relative weight compared with birth weight on waist–hip ratio in men and on waist circumference in men and women indicates a postnatal effect on adult abdominal obesity. Alternatively it may be argued that lightness in childhood was a more sensitive marker of impaired fetal growth than birth weight. Birth weight is a strong predictor of weight and height in childhood.[29] More specifically, despite catch-up growth in the first year of life,[30] babies born small for gestational age tend to be lighter and shorter than their peers in childhood,[31–33] and late adolescence,[30,34] particularly if they are male.[12] In this study childhood weight was adjusted for height whereas birth weight was unable to be adjusted for gestational age or birth length. This second interpretation is unlikely, particularly for men. First, the change of direction in the effect of relative weight at 7 on both waist–hip ratio and waist circumference among men after adjusting for adult BMI, and the positive association between birth weight and waist circumference that remains after adjustment for relative weight at 7 y, suggests an effect of weight gain after age 7 y on abdominal obesity which is independent of the effect of birth weight on waist circumference. Among women, the influence of relative weight on waist circumference reflects the same pattern as that for birth weight and hence separating out the effects of each body size measure is not so easy. Second, the inverse relationship between waist–hip ratio and childhood growth in men and waist circumference in men and women was weakest at age 4: if relative weight in childhood was a marker of fetal growth it would be expected that the relationship with waist–hip ratio would be strongest at the younger age.

Another possibility is that the risk of later abdominal obesity is higher in those born light who remained light in childhood but we found no variation in the effect of childhood relative weight on waist–hip ratio or waist circumference across birth weight categories, which suggests the link between poor childhood growth and adult abdominal obesity is independent of fetal growth and is likely to involve a different set of mechanisms other than impaired fetal growth. There may be clusters within the metabolic syndrome[7,25,35] and these clusters may differ in relation to patterns of growth. For example, McKeigue[25] postulated that impaired fetal growth was important in the 'small baby syndrome' characterised by hypertension, insulin resistance and glucose intolerance, but not in the 'central obesity syndrome' characterised by raised triglyceride levels, low high density lipoprotein cholesterol, insulin resistance and glucose intolerance. Perhaps the origins of central obesity syndrome may be traced to childhood? Certainly characteristics of the metabolic syndrome are known to cluster in childhood and track into adult life,[36,37] but high-risk subjects were obese, not thin, as children. This is consistent with studies that show a positive relationship between body build and insulin levels or insulin resistance in childhood[9,38] and the highest risk of the metabolic syndrome in those who had been obese since adolescence.[39]

Other studies support the idea that poor childhood growth[34,40–43] is linked to insulin resistance. Short children with intrauterine growth retardation were at greater risk of insulin resistance than controls of normal birth weight.[40] Short adult stature was associated with higher insulin levels,[34] low insulin response[41] and impaired glucose tolerance.[42] In one study of men,[41] this relationship was independent of birth weight; the other studies did not examine this. Studies of adults have to rely on final stature as a marker of childhood growth and cannot examine the influence of childhood weight. The addition of height at age 7 to our final models did not affect our findings with relative weight.

Thus it would seem that children who are thin as well as those who are obese may have a raised risk of central obesity, insulin resistance and diabetes. The relative importance of these two groups of children could have changed in later cohorts. Earlier born cohorts may have a greater proportion of children with poor childhood growth whereas later born cohorts have been more at risk of childhood obesity. In this study the growth trajectory with the lowest risk of adult abdominal obesity was represented by well nourished children who were heavier than their peers but grew up to be lean adults.

How can we explain the negative association between childhood weight and abdominal adiposity observed for given current body size in our study? Reversal of the childhood weight effect after adjusting for BMI is indicative of a growth effect between age 7 and adult life. Earlier age of onset of obesity or earlier puberty may be associated with a different pattern of body fat distribution. Waist–hip ratio in adolecence is an indicator of maturity,[44] but there is little evidence that early maturers become more centrally obese as adults. A study[45] showed that women who were obese as teenagers tended to have their weight concentrated on their hips more than their peers of comparable weight and age who were not obese as teenagers. Further research is needed on the effects of puberty and growth on adult body shape and its change with age.

In studies of adult waist–hip ratio,[3] diabetes and insulin levels[46] the effect of birth weight and other measures of early growth have generally been stronger in those with a greater BMI. Our finding of an attenuation of the effect for higher current BMI is counter to these previous findings and the reasons for it are unclear. There may be greater measurement error at higher levels of obesity or current fatness may overwhelm the relatively small effects of weight in early life.

This study, like others before, has focused on the small direct inverse effects of weight in early life on abdominal obesity in adult life. Of possible clinical significance is the fact that the risk of abdominal obesity (and therefore possibly diabetes) occurs at a lower level of BMI in those who were small in childhood compared with others. It is also worth stressing the positive indirect effects of weight in childhood and at birth on waist circumference and of weight in childhood on waist–hip ratio that were observed before adjustment for adult BMI. Those who were heavy in early life tend to become heavy adults and this positive relationship probably reflects increments in lean tissue more than increments in fat.[47] The combined effects of BMI, weight at birth and in childhood indicate that abdominal obesity is still determined to the great extent by adult body size.

In conclusion, this study found a small prenatal inverse effect of fetal growth on adult waist–hip ratio due to a reduced hip size in those who were small babies. Among men, those who were small babies also had smaller waists than others. There was also an inverse postnatal effect of childhood growth such that for any given adult body size those who had been lighter in childhood were more at risk of abdominal obesity. These relationships were independent of childhood socioeconomic circumstances and support the idea that insulin resistance may be linked to low weight in childhood.

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**References**

1 Barker DJP. *Mothers, babies and health in later life*, 2nd edn. Churchill Livingstone: Edinburgh; 1998.
2 Bjorntorp P. Abdominal fat distribution and disease: an overview of epidemiological data. *Ann Med* 1992; **24**: 15–18.
3 Law CM, Barker DJP, Osmond C, Fall CHD, Simmonds SJ. Early growth and abdominal fatness in adult life. *J Epidemiol Community Health* 1992; **46**: 184–186.
4 Fall CHD, Osmond C, Barker DJP, Clark PMS, Hales CN, Stirling Y, Meade TW. Fetal and infant growth and cardiovascular risk factors in women. *Br Med J* 1995; **310**: 428–432.
5 Han TS, Mcneill G, Campbell DM. The relationship between women's birth weight and their current intra-abdominal fatness. *Proc Nutr Soc* 1995; **54**: 182A.
6 Valdez R, Athens MA, Thompson GH, Bradshaw BS, Stern MP. Birthweight and adult health outcomes in a biethnic population in the USA. *Diabetologia* 1994; **37**: 624–631.
7 Byberg L, McKeigue PM, Zethelius B, Lithell HO. Birth weight and the insulin resistance syndrome: association of low birth weight with truncal obesity and raised plasminogen activator inhibitor-1 but not with abdominal obesity or plasma lipid disturbances. *Diabetologia* 2000; **43**: 54–60.
8 Barker M, Robinson S, Osmond C, Barker DJP. Birth weight and body fat distribution in adolescent girls. *Arch Dis Child* 1997; **77**: 381–383.
9 Bavdekar A, Yajnik CS, Fall CHD, Bapat S, Pandit AN, Deshpande V, Bhave S, Kellingray SD, Joglekar C. Insulin resistance syndrome in 8-year-old Indian children. *Diabetes* 1999; **48**: 2422–2429.
10 Ravelli ACJ, Van der Meulen JHP, Osmond C, Barker DJP, Bleker OP. Obesity at age 50 y in men and women exposed to famine prenatally. *Am J Clin Nutr* 1999; **70**: 811–816.
11 Phillips DIW, McLeish R, Osmond C, Hales CN. Fetal growth and insulin resistance in adult life: role of plasma triglyceride and nonesterified fatty acids. *Diabetic Med* 1995; **12**: 796–801.
12 Matthes JWA, Lewis PA, Davies DP, Bethel J. Body size and subcutaneous fat patterning in adolescence. *Arch Dis Child* 1996; **75**: 521–523.
13 Stanner SA, Bulmer K, Andres C, Lantseva OE, Borodina V, Poteen VV, Yudkin JS. Does malnutrition in utero determine diabetes and coronary heart disease in adulthood? Results from the Leningrad siege study, a cross sectional study. *Br Med J* 1997; **315**: 1342–1348.
14 Martyn CN, Hales CN, Barker DJP, Jespersen S. Fetal growth and hyperinsulinaemia in adult life. *Diabet Med* 1998; **15**: 688–694.
15 Lucas A, Fewtrell MS, Cole TJ. Fetal origins of adult disease — the hypothesis revisited. *Br Med J* 1999; **319**: 245–249.
16 Braddon FEM, Rodgers B, Wadsworth MEJ, Davies JMC. Onset of obesity in a 36 y birth cohort study. *Br Med J* 1986; **293**: 299–303.
17 Blane D, Davey Smith G, Gillis CR, Hole DJ, Hawthorne WM. The association of cardiovascular risk factors with socioeconomic position during childhood and during adulthood. *Br Med J* 1996; **313**: 1434–1438.
18 Wannamethee SG, Whincup PH, Shaper G, Walker M. Influence of fathers' social class on cardiovascular disease in middle-aged men. *Lancet* 1996; **348**: 1259–1263.
19 Hardy R, Wadsworth MEJ, Kuh D. The influence of childhood weight and socioeconomic status on change in adult body mass index in a British national birth cohort. *Int J Obes Relat Metab Disord* 2000; **24**: 725–734.
20 Teasdale TW, Sorensen TIA, Stunkard AJ. Genetic and early environmental components in sociodemographic influences on adult body fatness. *Br Med J* 1990; **300**: 1615–1618.
21 Brunner E, Juneja M, Marmot M. Abdominal obesity and disease are linked to social position. *Br Med J* 1998; **316**: 308–309.
22 Wadsworth MEJ, Kuh DJL. Childhood influences on adult health: a review of recent work in the British 1946 national birth cohort study, the MRC National Survey of Health and Development. *Paediat Perinat Epidemiol* 1997; **11**: 2–20.
23 Wadsworth MEJ, Mann SL, Rodgers B, Kuh DL, Hilder WS, Yusuf EF. Loss and representativeness in a 43 y follow-up of a national birth cohort. *J Epidemiol Community Health* 1992; **46**: 300–304.
24 Stark O, Atkins E, Wolff OH, Douglas JWB. Longitudinal study of obesity in the National Survey of Health and Development. *Br Med J* 1981; **283**: 13–17.
25 McKeigue P. Diabetes and insulin action. In: Kuh D, Ben-Shlomo Y (eds). *A life course approach to chronic disease epidemiology*. Oxford University Press: Oxford; 1997. pp 78–100.
26 Pouliot MC, Despres JP, Lemieux S, Moorjani S, Bouchard C, Tremblay A, Nadeau A, Lupien PJ. Waist circumference and abdominal sagittal diameter: best simple anthropometric indexes of abdominal visceral adipose tissue accumulation and related cardiovascular risk in men and women. *Am J Cardiol* 1994; **73**: 460–468.
27 Seidell JC, Björntorp J, Sjöström L, Sannerstedt R, Krotkiewski M, Kvist H. Regional distribution of muscle and fat mass in men–new insight into the risk of abdominal obesity using computed tomography. *Int J Obes* 1989; **13**: 289–303.
28 Phillips DIW. Birth weight and the future development of diabetes. A review of the evidence. *Diabetic Care* 1998; **21**: B150–B155.
29 Binkin NJ, Yip R, Fleshood L, Trowbridge FL. Birth weight and childhood growth. *Pediatrics* 1988; **82**: 828–834.

30 Karlberg J, Albertsson-Wikland K. Growth in full-term small-for-gestational-age infants: from birth to final height. *Pediatr Res* 1995; **38**: 733–739.
31 Strauss RS. Effects of the intrauterine environment on childhood growth. *Br Med Bull* 1997; **53**: 81–95.
32 Fisch RO, Bilek MK, Ulstrom R. Obesity and leanness at birth and their relationship to body habitus in later childhood. *Pediatrics* 1975; **56**: 521–528.
33 Douglas JWB, Mogford M. The results of a national inquiry into the growth of premature children from birth to 4 y. *Arch Dis Child* 1953; **28**: 436–445.
34 Leger A, Levy-Marchal C, Bloch J, Pinet A, Chevenne D, Porquet D, Collin D, Czernichow P. Reduced final height and indications for insulin resistance in 20 y olds born small for gestational age: regional cohort study. *Br Med J* 1997; **315**: 341–347.
35 Chen W, Srinivasan SR, Elkasabany A, Berenson GS. Cardiovascular risk factors clustering features of insulin resistance syndrome (syndrome X) in a biracial (black–white) population of children, adolescents, and young adults. *Am J Epidemiol* 1999; **150**: 667–674.
36 Bao W, Srinivasan SR, Wattigney WA, Berenson GS. Persistence of multiple cardiovascular risk clustering related to syndrome X from childhood to young adulthood. *Arch Intern Med* 1994; **154**: 1842–1848.
37 Raitakari OT, Porkka KVK, Rasanen L, Ronnemaa T, Vikari JSA. Clustering and six year cluster-tracking of serum total cholesterol, HDL-cholesterol and diastolic blood pressure in children and young adults. *J Clin Epidemiol* 1994; **47**: 1085–1093.
38 Whincup PJ, Cook DG, Adshead F, Taylor SJC, Walker M, Papacosta O, Alberti KMMM. Childhood size is more strongly related than size at birth to glucose and insulin levels in 10–11-year-old children. *Diabetologia* 1997; **40**: 319–326.
39 Vanhala M, Vanhala P, Kumpusalo E, Halonen P, Takala J. Relation between obesity from childhood to adulthood and the metabolic syndrome: population based study. *Br Med J* 1998; **317**: 319.
40 Chiarelli F, di Ricco L, Mohn A, De Martino M, Verrotti A. Insulin resistance in short children with intrauterine growth retardation. *Br Med J* 1999; **428**: 62–65.
41 Alvarsson M, Efendic S, Grill VE. Insulin responses to glucose in healthy males are associated with adult height but not with birth weight. *J Intern Med* 1994; **236**: 275–279.
42 Phipps K, Barker DJP, Hales CN, Fall CHD, Osmond C, Clark PMS. Fetal growth and impaired glucose-tolerance in men and women. *Diabetologia* 1993; **36**: 225–228.
43 Davey Smith G, Hart C. Insulin resistance syndrome and childhood social conditions. *Lancet* 1997; **349**: 284–285.
44 Tienboon P, Wahlqvist ML, Rutishauser IHE. Early life factors affecting body mass index and waist-hip ratio in adolescence. *Asia Pacific J Clin Nutr* 1992; **1**: 21–27.
45 Lanska DJ, Lanska MJ, Hartz AJ, Rimm AA. Factors influencing anatomic location of fat tissue in 52953 women. *Int J Obes Relat Metab Disord* 1985; **9**: 29–38.
46 Lithell HO, McKeigue PM, Berglund L, Mohsen R, Lithell U-B, Leon DA. Relation of size at birth to non-insulin dependent diabetes and insulin concentrations in men aged 50–60 y. *Br Med J* 1996; **312**: 406–410.
47 Kahn HS, Narayan KMV, Williamson DF, Valdez R. Relation of birth weight to lean and fat thigh tissue in young men. *Int J Obes Relat Metab Disord* 2000; **24**: 667–672.