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Birth weight, postnatal weight gain and adult body composition in five low and middle income countries

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Abstract

Objectives—Evaluate associations between birth weight (BW), infancy and childhood weight gain and adult body composition.

Methods—Subjects included participants of five birth cohort studies from low and middle income nations (Brazil, Guatemala, India, Philippines, South Africa; n=3432). We modeled adult body composition as a function of BW and conditional weight gain (CW), representing changes in weight trajectory relative to peers, in three age intervals (0-12m, 12-24m, 24m-mid childhood).

Results—In 34 of 36 site- and sex-specific models, regression coefficients associated with BW and CWs were higher for adult fat-free than for fat mass. The strength of coefficients predicting

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fat-free mass relative to those predicting fat mass was greatest for birth weight, intermediate for CWs through 24 months, and weaker thereafter. However, because fat masses were smaller and showed larger variances than fat-free masses, weaker relationships with fat mass still yielded modest but significant increases in adult % body fat (PBF). CW at 12 months and mid-childhood tended to be strongest predictors of PBF, while BW was generally the weakest predictor of PBF. For most early growth measures, a 1 SD change predicted less than a 1% change in adult body fat, suggesting that any health impacts of early growth on changes in adult body composition are likely to be small in these cohorts.

Conclusions—Birth weight and weight trajectories up to 24 months tend to be more strongly associated with adult fat-free mass than with fat mass, while weight trajectories in mid-childhood predict both fat mass and fat-free mass.

Keywords

body fat; cohort studies; developing countries; DOHaD; obesity

Introduction

Patterns of growth and weight gain during fetal life, infancy and childhood predict adult metabolic and cardiovascular diseases as a result of changes in organ growth, metabolic function, and other biological pathways (Barker 1990; 2003; Barker et al., 2009; Ben-Shlomo and Kuh 2002). Postnatal changes in body composition represent an important candidate mechanism by which early experience might influence adult chronic disease risk (Eriksson et al., 2001; Kuh et al., 2002; Laitinen et al., 2004; McCarthy et al., 2007; Victora et al., 2007). Notably, birth weight is positively related to later lean mass, which could help explain why lower birth weight individuals are at heightened risk for cardiovascular disease (Wells 2007; Yajnik 2002). Early growth-mediated changes in both the quantity and pattern of body fat deposition could also have effects on traits like insulin resistance, blood pressure and lipid metabolism, and is thus understood as an important pathway linking early developmental processes with adult health (Wells 2007).

In high-income countries, some studies report that rapid weight gain in the months immediately following birth predicts a more adverse body composition and metabolic risk profile in adulthood (Baird et al., 2005; Monteiro and Victora 2005; Ong et al., 2000). In contrast, others find that rapid weight gain later in childhood, rather than in infancy, predicts a more rapid onset of body fat deposition, increased obesity risk, and elevated risk for cardiovascular diseases (Reilly et al., 2005).

It is presently unclear whether early growth trajectories have distinct relationships with adult body composition in lower or middle income countries, where intergenerational histories of undernutrition are coupled with often rapid nutritional, lifestyle and weight change (Adair and Prentice 2004; Yajnik 2004). Past studies in several cohorts in these settings report evidence for stronger relationships between birth weight or infancy weight gain and adult lean mass than fat mass, with rapid weight gain in later childhood generally more strongly related to adult fat mass (Li et al., 2003; Sachdev et al., 2005; Victora et al., 2007). These findings support the promotion of infant and childhood growth in populations in which early life undernutrition, as manifest in growth faltering, is common (Victora et al., 2010).

The Consortium on Health Oriented Research in Transitional Societies (COHORTS) pools longitudinal data from 5 well-characterized long-term cohorts in middle or lower income populations to clarify the role of early life influences on a range of functional and health outcomes (Richter et al., in press). In this journal we recently reported strongest relationships between infancy growth faltering and adult height deficits in these populations

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(Stein et al., 2009). Here we expand upon these analyses to clarify the importance of early weight trajectories as predictors of adult body composition in these 5 cohorts. We used a uniform analysis strategy across populations to investigate the importance of birth weight and weight trajectories during different intervals of infancy and childhood as predictors of adult fat and fat-free mass.

Materials and methods

This study used data from five studies (Table 1) that are pooling resources and data as part of the Consortium on Health Orientated Research in Transitional Societies (COHORTS) (Richter et al., in press; Victora et al., 2008): the 1982 Pelotas Birth Cohort (Brazil) (Victora and Barros 2006), the Institute of Nutrition of Central America and Panama – INCAP Oriente Longitudinal Study (Guatemala)(Stein et al., 2008); the New Delhi Birth Cohort Study (India)(Bhargava et al., 2004); the Cebu Longitudinal Health and Nutrition Survey (Philippines)(Adair et al., 2011); and the Birth to Twenty cohort (South Africa)(Richter et al., 2004). The methods of each have been published in detail elsewhere (Victora et al., 2008). All studies were approved by an appropriate Ethics or Institutional Review Board.

Birth, infancy and childhood anthropometry

Birth weight (BW) was measured by the research teams in Brazil, India, and Guatemala. In the Philippines, BW was measured by birth attendants provided with hanging scales for home births or was obtained from hospital records for hospital births. In South Africa, BW was obtained from birth records. In all studies, weights during infancy and childhood were measured by research teams. We identified four child ages at which weight was measured in all five cohorts, namely birth, 12 mo, 24 mo, and an age we denote as mid-childhood, which varies across cohorts (48 mo in Brazil, Guatemala and India, 60 mo in South Africa, and 102 mo in Philippines). In India, weights corresponding to the age intervals of the study were interpolated using individual weight curves. We computed age and sex-specific Z-scores using the WHO Growth Standards (2006). We interpolated weight at 48 mo in the South Africa and Philippine samples by linear interpolation of the WAZ at 24 mo and mid-childhood and back-transformation of the WAZ at 48 mo to the absolute weight.

Conditional weight

Weight estimates measured at different ages are strongly correlated, leading to problems of collinearity if models simultaneously evaluate body size at different ages as predictors of adult outcomes. We therefore modeled relationships between early weight and adult outcomes using conditional weights (CW)(Adair et al., 2009). For each time point in infancy and childhood, CW was calculated as the residual from site- and sex-stratified linear regression of weight (kg) at that age on BW and any prior postnatal weights. The models were also adjusted for exact age at the time of measurement and a squared age term to account for any non-linearities. As residuals, the CW are uncorrelated with all prior weight measures. When entered into a multiple regression including BW and all prior CW estimates, CW may be interpreted as the deviation in the preceding growth interval from the weight predicted by BW, any prior CWs, and the population- and sex-specific mean growth.

Adult anthropometry and body composition

Adult height and weight were obtained by research teams using standard methods. Adult body fat and fat-free mass were calculated using site-specific methods. In Brazil, bioelectrical impedance was measured and these results were corrected on the basis of a validation study that used isotopic methods (Wells et al., 2003); these data are only available for males. In Guatemala, weight, height, and abdominal circumference were obtained and entered into a hydrostatic-weighing validated equation (Ramirez-Zea et al., 2006). The India

and Philippine cohorts used published equations (Durnin and Womersley 1974) that have been validated for use in Asian populations for estimating body fat from skinfold measures (Deurenberg et al., 2002); South Africa used dual x-ray absorptiometry (Hologic Delphi). Fat mass was calculated as % body fat x body weight, and fat-free mass as weight - fat mass. Pregnant women were excluded from all analyses. The body mass index (BMI) was calculated as kg/m^2, which was used to define overweight (BMI ≥ 25 kg/m^2) and obesity (BMI ≥ 30 kg/m^2). Because the South African sample was less than 18 years of age, in this cohort overweight and obesity status were defined using the zbmicat command in Stata, which defines overweight and obesity status using age- and sex-specific cut points recommended by the Childhood Obesity Working Group of the International Obesity Taskforce (Cole et al., 2000).

Control variables

Age at adult measurement was entered as a continuous variable. In females, we adjusted for parity – including prior live births (Brazil, India, Guatemala) or all prior pregnancies, including stillbirths, live births and premature terminations (Philippines). None of the participants in the South Africa cohort had given birth at the time of body composition measurement. Height was included in the models predicting fat and fat-free mass.

Statistical analysis

All statistical analyses were conducted using Stata (version 10, College Station, TX). Subsamples with all necessary variables were defined and descriptive statistics were calculated. In constructing models, we first tested to see if key relationships varied significantly by gender and across site. There was significant heterogeneity by gender for models predicting fat mass ($F_{4,3421}$ = 20.15, p<0.00001) and fat-free mass ($F_{4,3421}$ = 33.20, p<0.00001). In gender-stratified models, there was significant heterogeneity among males across sites in relationships between early growth measures and both fat ($F_{16,2051}$= 1.94, p<0.014) and fat-free mass ($F_{16,2051}$ = 4.93, p<0.00001), and among females for fat ($F_{12,1329}$= 3.74, p<0.00001) and fat-free mass ($F_{12,1329}$ = 4.80, p<0.00001). Therefore, all models reported here were run separately by gender and site. In analyses predicting fat mass, two models are presented: the first is unadjusted, and the second adjusted for age and height (and in females, also parity).

A central question addressed in this paper is whether early weight gain during different intervals of infancy and childhood has different relationships with adult fat-free and fat mass. We used multivariate regression models to simultaneously predict fat-free mass and fat mass from birth weight and conditional weights at 12, 24 months and mid-childhood. All predictors (birth weight and CW scores) and outcomes (fat-free mass and fat mass) were run as site- and gender-specific standard deviation scores. Thus, the coefficients from these models may be interpreted as partial correlations, allowing direct comparison of the relative strength of relationships between each predictor and outcome and between coefficients calculated at different sites. For each predictor, post-estimation tests were used to evaluate whether the regression coefficients predicting adult fat-free and fat mass differed. Finally, we ran comparable site- and sex-stratified models predicting adult % body fat as an outcome.

Results

Early life and adult characteristics of the study sample are summarized in Table 2. With the exception of Brazil, birth weights were between roughly 0.5 and 1.0 SD below the WHO norm. Average weight-for-age Z-score declined between birth and 24 months in Guatemala and India and between birth and mid-childhood in the Philippines, with comparably stable

WAZ scores between birth and mid-childhood in South Africa and Brazil. Mean adult height among the males ranged between 1.63 m in Guatemala and Philippines to 1.74 m in Brazil, and among females, between 1.51 m in Guatemala and Philippines to 1.59 m in South Africa. As adults, the Philippine sample was the leanest as indicated by the body mass index, with less than 10% of males and females classified as overweight or obese. At the other extreme, 58% of the Guatemalan females in the sample were classified as overweight or obese.

With few exceptions, CW tended to be positively related to adult fat mass at all ages and sites and in both genders, although there was heterogeneity in these relationships (Table 3). Among males, CW at 12 months and in mid-childhood were strongest predictors of adult fat mass in Brazil, Guatemala, India and the Philippines with CW at 48 months strongest in South Africa. In females, a similar pattern was present for the Philippines and South Africa but not Guatemala or India where birth weight or CW at 12 months tended to be strongest predictors of fat mass. These relationships were largely unchanged after adjustment for height and age (and in females parity). Conditional weight scores tended to relate to fat-free mass in a similar pattern across sites and genders (Table 4). However, the strength of relationships varied by outcome and gender. Comparing findings from Table 3 and Table 4, each SD-score change in CW predicted roughly double the kg change in adult fat-free mass compared to the predicted change in adult fat mass among males, while coefficients predicting adult fat-free and fat mass were more comparable among females. Unlike the models predicting fat mass, coefficients relating CW scores with FFM were substantially attenuated in every site and in both genders after adjustment for adult height.

We next used multivariate regression to evaluate the relative strength of coefficients relating CW scores at different ages to model adult fat-free mass and fat mass simultaneously as outcomes. Fat mass and fat-free mass were modeled as site- and gender-specific SD-scores to allow direct comparison of their respective coefficients, which can be interpreted as partial correlations. In these models, the coefficients for fat-free mass were greater than those for fat mass in 34 of 36 comparisons (Table 5). In formal post-estimation tests comparing the strength of relationships between each CW score and fat-free and fat mass, there was consistent evidence across sites and genders for stronger effects of birth weight on fat-free mass than on fat mass (in 8 of 9 models) and for no differential effects of CW at mid-childhood on fat-free mass or fat mass (in 8 of 9 models). There was more site- and gender-specific heterogeneity in effects of CW measured at the intervening ages, with CW at both 12 and 24 months a stronger predictor of fat-free mass than fat mass in only 4 of 9 models.

The multivariate models showed that nearly all BW or early CW measures were more strongly correlated with changes in fat-free mass than with fat mass, when these are expressed as Z scores. Fat masses tend to equal 1/3 to $1/5^{th}$ of fat-free masses in our cohorts (Table 2), but fat mass (coefficients of variation of 10-15%) was more variable than fat-free mass (coefficients of variation around 30-70%). This implies that a relatively weaker effect on fat mass Z scores could still increase the percentage of adult body weight accounted for by fat. To test this possibility, a final set of models (Table 6) evaluated relationships between BW and CW scores and adult % body fat adjusting for age and in females also parity. Consistent with this expectation, nearly all early growth measures predicted a positive change in % body fat. Among males, CW at 12 months and mid-childhood CW tended to be strongest predictors of % body fat at each site, with mid-childhood CW the strongest coefficient in all cohorts. Among all male cohorts but South Africa, BW was the weakest predictor of % body fat. Among females, the Philippines and South Africa followed a pattern similar to that of the males, with % body fat most strongly related to CW at 12 months and in mid-childhood. However, there was more heterogeneity across female

cohorts: birth weight was the strongest predictor of % body fat in Guatemala, while in India % body fat was most strongly related to BW and 12 month CW.

Discussion

We address an important public health problem using a uniform modeling approach and a common analytic strategy in five well-characterized cohorts representing different political-economic, cultural, and nutritional circumstances. Despite differences in economic and other conditions across populations and in methods used to measure body composition, we found certain consistencies across the five sites. We also found that results were contingent upon the body composition measure employed. When adult body composition was modeled as separate compartments of fat-free and fat mass, birth weight tended to be a stronger predictor of adult fat-free mass than of fat mass irrespective of gender and site, consistent with prior evidence of beneficial effects of fetal growth on adult body composition (Singhal et al., 2003; Wells et al., 2007). In contrast, CW measured in mid-childhood was not differentially related to fat-free or fat mass in adulthood in any site or gender, pointing to fewer potential benefits to lean tissue in relation to weight gain at older ages. Modeling % body fat as an outcome revealed that the correlations of most BW and CW scores with fat mass, although weaker than correlations with those with fat-free mass when both are expressed in standardized units, were sufficient to modestly increase % body fat. In males, BW was generally the weakest predictor of % body fat. Although there was heterogeneity across models, CW at 12 months, reflecting weight gain in the first year of life, and mid-childhood CW, reflecting early childhood weight gain, tended to be the strongest predictors of adult % body fat in both genders. These findings show that patterns of early life weight gain predict adult body composition, while also documenting heterogeneity in these relationships by gender and across populations.

Modeling relationships between early weight gain and adult fatness requires grappling with several issues, including the choice of outcomes, the age ranges of early life weight gain to be investigated as predictors, and the related statistical problem that weight gain in a given age interval tends to be highly correlated with gain in adjacent intervals. With respect to the first issue, adult body mass index (BMI) is a commonly reported outcome in studies of early life determinants of adult body composition, with consistent positive associations being reported with birth weight and faster weight gains in infancy and childhood (Baird et al., 2005; Monteiro and Victora 2005). Because BMI does not separate fat from fat-free mass, such results must be interpreted with caution. As an alternative approach, we investigated fat mass as an outcome, and evaluated whether early weight trajectories are associated more strongly with fat than with fat-free mass in adulthood. In our view, this is a useful approach, because one would like children to build up fat-free mass without gaining excess body fat as adults. Finally, we also considered the % of body weight that is fat as an outcome, which provides insight into how differential effects on lean and fat compartments contribute to changes in body composition.

The second set of issues involve how best to model early weight trajectories as predictors of adult body composition. Past work has shown that it is important to separate the long-term effects of early and later childhood weight gain (Victora et al., 2008). Some of the first studies on the long-term consequences of growth patterns in childhood reported on weight gains from birth to school age (Eriksson et al., 2001; Parsons et al., 2001), and were therefore unable to identify age ranges associated with different risks. We opted to model the relationship between early weight during different intervals from birth to mid-childhood, which allowed us to tease apart the relative importance of change in weight at different ages to adult fat and fat-free mass. However, because weight at the end of an age range is the same as the weight at the beginning of the next range, collinearity would be unavoidable if

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simple weight gains or weight velocities were modeled as independent predictors. To avoid this problem, we used conditional weight scores, which estimate the effect of that component of weight gain in each interval that is independent of gain in prior intervals.

We found that associations relating early CW scores to adult body composition were not consistent for males and females, and in addition varied substantially across sites. We anticipated heterogeneity across sites in light of the many factors that differentiated the sites and that we were not able to fully control in our models. Notably, the age at which subjects had their adult body composition measured varied by site, as did the method used to estimate fat and fat-free mass. In addition, the populations varied in prevalence of low birth weight, early life undernutrition and adult overweight, reflecting diverse settings in which the nutrition and epidemiologic transitions have had differential influences on adult health and nutritional status. The significant heterogeneity in the pattern and magnitude of coefficients across site and by gender required that we pursue stratified rather than pooled models. Nevertheless, underlying consistencies were apparent across the sites that point to the differential importance of weight gain in different early life age intervals as predictors of distinct components of adult body composition.

Conditional weight scores are positive when growth in the preceding interval was faster than expected based upon that individual's weight trajectory entering that interval and the mean population growth during the interval. Thus, we interpret our conditional weight models as indicating that faster than expected weight gains from birth to 12 months and from 24 months to mid childhood tend to be more strongly associated with adult fat mass than are birth weight or relatively rapid weight gain from 12-24 months. Adjusting for height attenuated coefficients predicting fat-free mass, especially in males, but left coefficients predicting fat mass largely unchanged. This suggests that early weight gain influences fat-free mass in part via effects on adult stature, consistent with prior analysis in these cohorts (Stein et al., 2009).

Certain consistencies emerged across sites when we modeled fat and fat-free mass simultaneously as outcomes. Here fat and fat-free mass were modeled as site- and sex-specific SD scores, thus allowing for a direct comparison of effect sizes of each CW score predicting fat and fat-free mass while also taking into account the average differences in adult fat-free mass between males and females. In these models, birth weight and to a lesser extent CW in the first two years of life tended to be more strongly associated with fat-free than with fat mass, but this differential effect on fat-free mass was absent in 8 of 9 models by mid-childhood.

The average adult fat-free mass tended to be 3-5 times the mass of fat in the cohorts considered here, while variability for fat mass was also larger. Thus, even relatively weaker relationships between early growth and adult fat mass than for fat-free mass could increase the proportion of adult weight accounted for by fat. Our models predicting % body fat confirmed this expectation. With few exceptions, faster earlier growth at any interval predicted an increase in adult % body fat in both males and females. Although the strength of these effects did vary by age, gender and site, there were certain consistencies across many of the cohorts, and in general findings mirrored trends seen in models predicting fat mass and fat-free mass. Just as CW at 12 months and mid-childhood tended to be strongest predictors of fat mass (Table 3), the weight gain represented in these intervals generally predicted the largest % increase in adult body fat. In the males, mid-childhood CW was the strongest predictor of % body fat in all the cohorts, while BW was the weakest predictor of % body fat among all male cohorts but South Africa. Among females, CW at 12 months and in mid-childhood tended to be strongest predictors of % body fat.

Although many early growth measures were significant predictors of adult % body fat, these effects were generally small. A full standard deviation change in most early growth measures, which represents a large change in early weight trajectory, predicted on average a 0.85 % change in adult body fat. The health impacts of a change of this magnitude are likely to be negligible in most of our cohorts, many of whom are relatively lean. Based upon these modest effect sizes, it seems likely that the many benefits to health and function known to result from improvements in early nutrition and growth (e.g. Victora et al 2008) will outweigh any negative effects on health operating through changes in body composition.

Previously published single-site analyses of our cohorts are generally in line with the findings reported here, despite the fact that these analyses did not rely on conditional weights and none modeled fat and fat-free mass simultaneously. In Brazil, adult height was primarily determined by fetal and infant growth, whereas weight-related indices were more strongly influenced by later growth (Victora et al., 2007). In India, BMI changes in infancy and early childhood were correlated more strongly with adult lean mass than with adiposity or central adiposity, whereas BMI changes in late childhood or adolescence were associated with increased adult adiposity and central adiposity (Sachdev et al., 2005). In Guatemala, BMI in infancy and later childhood was positively associated with adult BMI, % fat, abdominal circumference, and fat-free mass; after the age of three years, associations were stronger with BMI, % fat and abdominal circumference than with fat-free mass (Corvalan et al., 2007). In a recent analysis of the Philippine cohort, weight gain from birth to 6 months of age was found to be an especially strong predictor of adult stature, fat-free mass, and strength in males but these relationships were weaker in females (Kuzawa et al 2010).

Other studies in high income populations have addressed these issues. Positive associations between birth weight and lean mass – to a greater extent than with fat mass – have been reported in the United Kingdom (Singhal et al., 2003) and from a younger cohort in Brazil (Wells et al., 2005). Also, the finding that weight gain from 24 months to mid-childhood is a stronger predictor of adult adiposity than is earlier weight gains has been reported in cohorts from the United Kingdom (Ong et al., 2000), Brazil (Wells et al., 2005), and Sweden (Ekelund et al., 2007). At the same time, the relatively low average birth weight of most of our study populations underscores the distinct starting point of growth trajectories in these settings compared to most higher income populations. Future studies in high income nations employing the analysis approach used here would help clarify how the predictors of adult body composition might vary across these contexts.

The different strengths of the coefficients linking CW during the first and second years of life with adult body composition may partly reflect absolute differences in weight gain during each growth interval or the increasing stability of growth trajectories as children mature. In our cohorts, absolute gains in body weight during the first year of life were roughly three times the gains in the second year of life (Table 2), suggesting a greater potential for variation in early postnatal growth to influence adult body composition. In addition, there may be important biological critical periods during specific developmental windows, such as the early postnatal surge in sex steroid production (Winter et al., 1976), which could influence body composition development and the pattern of gender differences in adult body composition (Kuzawa et al., 2010).

Our observational data can reveal patterns of association but cannot speak to causes. Indeed, it is possible that part of the association between early conditional weight and adult body composition reflects the pleiotropic effects of genes. Polymorphic loci with effects on early weight growth patterns have been identified (Sovio et al., 2009), and if such genes also influence adult body composition, this could lead to correlations between early conditional weight scores and adult body composition (Suarez et al., 1997). Although we cannot rule out

such effects, prior research conducted in the cohorts analyzed here (Stein et al., 2009; Victora et al., 1987), and in populations living under similar socioeconomic and political-economic settings (Billewicz and McGregor 1982), has underscored the overwhelming importance of environmental factors like nutrition, infant feeding practices, and early life infectious morbidity as determinants of skeletal growth and weight gain during the first 2-3 years of postnatal life, highlighting the potential for environmental contributions to the relationships that we document.

Additional limitations of the analyses reported here warrant mention. As alluded to above, methods for measuring adult body composition varied by site and some of the between-site heterogeneity undoubtedly reflects biases inherent in these methods. Although this limits the conclusions that we may draw regarding population differences, these concerns apply less to our findings of sex differences, which were found within site using common methods. The instruments used to measure diet, lifestyle, or environmental conditions across our five sites were also not directly comparable, which constrained our ability to adjust for potentially important covariates.

Although our analyses were limited by the ages at which weight measurements were available across sites, these measures allowed us to probe impacts at age intervals previously shown to be important as predictors of adult body composition in other populations. The ages of adult body composition measurement were more variable across sites, which likely contributed to the heterogeneity in relationships that we document. In this respect, the generally weaker relationships between early growth and fat-free mass among the South African males might partially reflect their relatively young age (~15.5 years), and the fact that males would have been at various stages of puberty and adult height attainment when body composition was measured. Future analysis of this cohort after they have achieved final adult stature would help clarify the importance of this source of biological variation as an influence on the relationships documented here. While our focus here has been on body composition per se, future work should also evaluate associations with regional fat patterning, as this may be an important link between early growth processes and the metabolic syndrome and cardiovascular disease risk (Despres and Lemieux 2006).

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TABLE 1

Overview of the five studies included in the analysis and description of body composition measurements

Cohort country (name)	Design	Cohort inception (year)	Adult follow-up (year)	Number included in analysis (n)	Initial cohort	Body composition measurement
Guatemala (INCAP)	Community intervention	1969-77	2004	205	Intervention trial of high-energy and protein supplement in women and children <7yrs in 1969 and born during 1969-77 in 4 villages.	Hydrostatic-weighing validated equation using weight, height, and abdominal circumference
India (Delhi)	Prospective cohort	1969-72	1998-2002	936	Babies born to a population of married women living in a defined area of Delhi. Primarily middle-class sample.	Predictive equation using triceps and subscapular skinfolds.
Philippines (CLHNS)	Prospective cohort	1983-4	2005	1,612	Pregnant women living in 33 randomly selected neighborhoods; 75% urban, all social classes.	Predictive equation using triceps and subscapular skinfolds.
South Africa (Birth-to-20)	Prospective cohort	1990	2005	302	Babies born to pregnant women living in defined urban area, primarily poor, black sample.	Dual X-ray Absorptiometry (DEXA).
Brazil (Pelotas)	Prospective cohort	1982	2005	377 (males only)	99% of all births in City's maternity hospital in 1982. All social classes.	Deuterium-validated equation using bioelectrical impedance. Only available for males.

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TABLE 2

Descriptive characteristics of cohorts during early life and at adult follow-up[a]

	Guatemala		India		Philippines		South Africa		Brazil
	Male (n=114)	**Female (n=91)**	**Male (n=540)**	**Female (n=396)**	**Male (n=887)**	**Female (n=725)**	**Male (n=160)**	**Female (n=142)**	**Male (n=377)**
Weight (kg)									
Birth	3.1 (0.6)	3.0 (0.4)	2.9 (0. 5)	2.8 (0.4)	3.0 (0.4)	3.0 (0.4)	3.2 (0.5)	3.0 (0.5)	3.3 (0.5)
12 months	7.9 (1.1)	7.7 (1.0)	8.5 (1.1)	7.9 (1.1)	8.3 (1.0)	7.7 (0.9)	9.7 (1.4)	9.1 (1.3)	9.8 (1.2)
24 months	9.9 (1.1)	9.6 (1.0)	10.4 (1.3)	9.7 (1.2)	10.1 (1.1)	9.5 (1.1)	11.7 (1.7)	11.2 (1.6)	12.3 (1.4)
Mid-childhood[b]	13.8 (1.4)	13.4 (1.4)	14.0 (1.6)	13.2 (1.6)	13.2 (1.8)	12.9 (1.8)	16.2 (1.8)	15.6 (1.8)	16.7 (2.4)
WAZ[c]									
Birth	−0.59 (1.22)	−0.53 (0.97)	−1.03 (1.00)	−1.07 (0.90)	−0.71 (0.93)	−0.57 (0.97)	−0.45 (1.17)	−0.69 (1.12)	−0.06 (1.15)
12 months	−1.83 (1.20)	−1.31 (1.06)	−1.20 (1.14)	−1.16 (1.14)	−1.47 (1.08)	−1.36 (1.03)	−0.09 (1.31)	0.06 (1.09)	0.002 (1.13)
24 months	−1.89 (1.01)	−1.53 (0.89)	−1.45 (1.05)	−1.44 (1.07)	−1.67 (0.97)	−1.68 (1.00)	−0.56 (1.30)	−0.41 (1.24)	−0.12 (1.07)
Mid-childhood[b]	−1.37 (0.80)	−1.41 (0.77)	−1.27 (0.89)	−1.52 (0.91)	−2.00 (1.04)	−1.85 (0.93)	−0.21 (0.96)	−0.31 (0.93)	0.06 (1.18)
Adult									
Age (years)	31.4 (1.2)	31.2 (1.2)	29.4 (1.3)	29.4 (1.3)	21.5 (0.3)	21.5 (0.3)	15.6 (0.3)	15.6 (0.2)	23.1 (0.3)
Height (cm)	162.8 (6.2)	151.4 (5.2)	169.5 (6.1)	155.1 (5.7)	163.1 (5.8)	151.1 (5.4)	166.5 (7.7)	158.8 (6.5)	173.8 (6.4)
Weight (kg)	63.7 (10.4)	60.6 (10.0)	72.0 (14.0)	59.5 (13.2)	56.0 (9.3)	46.4 (8.2)	55.6 (12.1)	54.6 (10.1)	74.0 (15.2)
Fat-free mass (kg)	51.0 (5.4)	39.1 (3.1)	53.9 (8.0)	38.4 (5.8)	46.4 (5.7)	31.0 (4.2)	45.9 (6.8)	36.5 (4.6)	61.1 (10.2)
Fat mass (kg)	12.7 (6.1)	21.4 (7.3)	18.1 (6.9)	21.1 (8.0)	9.7 (4.5)	15.4 (4.7)	9.8 (7.9)	18.2 (7.1)	12.9 (5.6)
% Body fat	19.2 (6.1)	34.4 (6.0)	24.4 (5.7)	34.3 (7.0)	16.7 (5.1)	32.7 (4.8)	16.4 (8.3)	32.3 (7.0)	16.8 (3.9)
BMI (kg/m^2)	24.0 (3.4)	26.4 (4.0)	25.0 (4.3)	24.6 (5.0)	21.0 (3.0)	20.3 (3.2)	20.0 (3.7)	21.7 (3.8)	24.5 (4.6)
Overweight[d]	26%	40%	39%	34%	8%	7%	7%	14%	29%
Obese[d]	7%	18%	10%	13%	2%	1%	4%	6%	10%
Parous		85%		75%		31%		0%	

[a] mean (SD) unless otherwise noted (see Methods for references to published profiles of each cohort).

[b] 48 mo in Brazil, Guatemala and India, 60 mo in South Africa, 102 mo in Philippines; South Africa and Philippine data interpolated to 48 mo (see methods)

[c] weight-for-age Z-score (WHO 2006 reference)

$d_{25kg/m^2 \leq BMI < 30kg/m^2}$, $BMI \geq 30kg/m^2$, For South Africa: International Obesity Task Force cut points (see Methods)

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TABLE 3

Coefficients from multiple regression models relating standardized conditional weight scores to adult fat mass (kg)

	Males						Females					
	Unadjusted			Adjusted[a]			Unadjusted			Adjusted[a]		
	β	**95% CI**	**P**	***β***	**95% CI**	**P**	***β***	**95% CI**	**p**	***β***	**95% CI**	**p**
Guatemala												
Birth	0.70	(−0.42 , 1.82)	0.22	0.41	(−0.90, 1.71)	0.54	1.86	(0.37, 3.35)	0.02	1.62	(0.06, 3.18)	0.05
12m	1.04	(−0.13, 2.21)	0.09	0.90	(−0.34, 2.13)	0.15	1.16	(−0.33, 2.65)	0.13	0.53	(−1.20, 2.26)	0.55
24m	0.53	(−0.57, 1.63)	0.34	0.37	(−0.81, 1.55)	0.54	1.29	(−0.18, 2.76)	0.09	0.87	(−0.75, 2.48)	0.29
Mid-childhood	0.91	(−0.26, 2.07)	0.13	0.82	(−0.38, 2.02)	0.18	0.74	(−0.84, 2.33)	0.36	0.52	(−1.12, 2.16)	0.54
R^2		0.07			0.07			0.11			0.17	
India												
Birth	1.05	(0.52, 1.58)	0.0001	0.74	(0.23, 1.26)	0.005	1.76	(1.04, 2.48)	0.0001	1.58	(0.85, 2.32)	0.0001
12m	1.79	(1.26, 2.33)	0.0001	1.56	(1.00, 2.12)	0.0001	2.37	(1.64, 3.10)	0.0001	2.00	(1.20, 2.80)	0.0001
24m	1.29	(0.75, 1.83)	0.0001	1.22	(0.70, 1.74)	0.0001	1.10	(0.38, 1.81)	0.003	0.92	(0.20, 1.64)	0.02
Mid-childhood	1.51	(0.98, 2.05)	0.0001	1.52	(1.01, 2.04)	0.0001	1.23	(0.50, 1.97)	0.001	1.28	(0.54, 2.02)	0.001
R^2		0.17			0.29			0.19			0.23	
Philippines												
Birth	0.35	(0.11, 0.60)	0.004	0.43	(0.18, 0.68)	0.001	0.81	(0.53, 1.08)	0.0001	0.82	(0.53, 1.10)	0.0001
12m	1.73	(1.46, 1.99)	0.0001	1.89	(1.60, 2.18)	0.0001	1.37	(1.07, 1.66)	0.0001	1.40	(1.07, 1.72)	0.0001
24m	0.59	(0.34, 0.84)	0.0001	0.65	(0.39, 0.91)	0.0001	0.46	(0.18, 0.75)	0.002	0.40	(0.11, 0.70)	0.008
Mid-childhood[b]	1.91	(1.67, 2.16)	0.0001	2.03	(1.77, 2.28)	0.0001	2.25	(1.98, 2.53)	0.0001	2.26	(1.97, 2.55)	0.0001
R^2		0.33			0.34			0.35			0.36	
South Africa												
Birth	1.69	(0.54, 2.84)	0.004	1.89	(0.68, 3.10)	0.002	0.56	(−0.44, 1.56)	0.272	1.07	(0.05, 2.09)	0.04
12m	1.61	(0.40, 2.82)	0.009	1.86	(0.56, 3.16)	0.005	3.10	(2.07, 4.13)	0.0001	3.62	(2.57, 4.67)	0.0001
24m	0.76	(−0.38, 1.90)	0.19	0.87	(−0.30, 2.03)	0.145	0.43	(−0.56, 1.42)	0.40	0.78	(−0.18, 1.75)	0.12
Mid-childhood[b]	2.07	(0.94, 3.19)	0.0001	2.29	(1.09, 3.50)	0.0001	2.50	(1.46, 3.54)	0.0001	3.17	(2.10, 4.23)	0.0001
R^2		0.16			0.17			0.30			0.36	

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	Males						Females					
	Unadjusted			Adjusted[a]			Unadjusted			Adjusted[a]		
	β	95% CI	P	β	95% CI	P	β	95% CI	p	β	95% CI	p
Brazil												
Birth	0.98	(0.51, 1.45)	0.0001	0.92	(0.43, 1.42)	0.0001						
12m	1.51	(1.02, 2.00)	0.0001	1.45	(0.93, 1.97)	0.0001						
24m	1.49	(1.00, 1.97)	0.0001	1.43	(0.93, 1.94)	0.0001						
Mid-childhood	2.16	(1.70, 2.62)	0.0001	2.16	(1.70, 2.62)	0.0001						
R^2		0.33			0.34							

[a] adjusted for age, height and in females also for parity,

[b] interpolated (see Methods)

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TABLE 4

Coefficients from multiple regression models relating standardized conditional weight scores to adult fat-free mass (kg)

	Males						Females					
	Unadjusted			Adjusted[a]			Unadjusted			Adjusted[a]		
	β	**95% CI**	**P**	***β***	**95% CI**	**p**	***β***	**95% CI**	**p**	***β***	**95% CI**	**p**
Guatemala												
Birth	2.31	(1.48, 3.15)	0.0001	0.90	(0.08, 1.72)	0.031	1.13	(0.55, 1.70)	0.0001	0.75	(0.22, 1.28)	0.006
12m	1.34	(0.47, 2.22)	0.003	0.63	(−0.15, 1.40)	0.112	1.02	(0.44, 1.59)	0.001	0.33	(−0.26, .92)	0.274
24m	1.48	(0.66, 2.30)	0.001	0.67	(−0.07, 1.41)	0.075	0.72	(0.15, 1.28)	0.013	0.26	(−0.29, 0.82)	0.343
Mid-childhood	1.19	(0.31, 2.06)	0.008	0.80	(0.04, 1.55)	0.038	0.50	(−0.11, 1.11)	0.107	0.26	(−0.30, 0.82)	0.363
R^2		0.34			0.54			0.28			0.47	
India												
Birth	1.65	(1.08, 2.22)	0.0001	1.03	(0.47, 1.58)	0.0001	1.62	(1.15, 2.09)	0.0001	1.20	(0.73, 1.66)	0.0001
12m	3.21	(2.64, 3.78)	0.0001	2.12	(1.52, 2.73)	0.0001	2.18	(1.70, 2.66)	0.0001	1.43	(0.92, 1.94)	0.0001
24m	1.79	(1.22, 2.37)	0.0001	1.28	(0.72, 1.84)	0.0001	1.35	(0.88, 1.82)	0.0001	1.02	(0.56, 1.48)	0.0001
Mid-childhood	2.04	(1.47, 2.61)	0.0001	1.55	(0.99, 2.10)	0.0001	1.08	(0.59, 1.56)	0.0001	0.89	(0.42, 1.36)	0.0001
R^2		0.31			0.39			0.32			0.40	
Philippines												
Birth	1.21	(0.95, 1.47)	0.0001	0.90	(0.65, 1.16)	0.0001	1.14	(0.92, 1.37)	0.0001	0.90	(0.68, 1.13)	0.0001
12m	2.83	(2.55, 3.11)	0.0001	2.18	(1.88, 2.47)	0.0001	1.38	(1.14, 1.62)	0.0001	1.02	(0.77, 1.28)	0.0001
24m	1.25	(0.98, 1.52)	0.0001	0.95	(0.68, 1.21)	0.0001	0.61	(0.37, 0.84)	0.0001	0.36	(0.13, 0.59)	0.002
Mid-childhood[b]	2.74	(2.48, 3.01)	0.0001	2.31	(2.04, 2.57)	0.0001	2.08	(1.86, 2.31)	0.0001	1.80	(1.57, 2.03)	0.0001
R^2		0.52			0.57			0.44			0.51	
South Africa												
Birth	2.05	(1.20, 2.89)	0.0001	1.04	(0.35, 1.73)	0.004	1.80	(1.30, 2.30)	0.0001	1.38	(0.89, 1.88)	0.0001
12m	2.32	(1.44, 3.21)	0.0001	1.12	(0.38, 1.87)	0.003	2.11	(1.59, 2.62)	0.0001	1.66	(1.16, 2.17)	0.0001
24m	0.82	(−0.02, 1.65)	0.056	0.38	(−0.28, 1.05)	0.259	1.29	(0.80, 1.78)	0.0001	1.09	(0.63, 1.56)	0.0001
Mid-childhood[b]	2.94	(2.11, 3.77)	0.0001	1.84	(1.15, 2.53)	0.0001	1.75	(1.23, 2.27)	0.0001	1.32	(0.81, 1.84)	0.0001
R^2		0.39			0.63			0.57			0.64	
Brazil												
Birth	2.70	(1.89, 3.52)	0.0001	2.04	(1.20, 2.87)	0.0001						

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	Males						Females					
	Unadjusted			Adjusted[a]			Unadjusted			Adjusted[a]		
	β	95% CI	P	β	95% CI	p	β	95% CI	p	β	95% CI	p
12m	2.97	(2.12, 3.83)	0.0001	2.32	(1.45, 3.19)	0.0001						
24m	3.17	(2.32, 4.01)	0.0001	2.57	(1.71, 3.42)	0.0001						
Mid-childhood	3.54	(2.75, 4.34)	0.0001	3.41	(2.63, 4.19)	0.0001						
R^2		0.39			0.42							

[a] adjusted for age, height and in females also for parity,

[b] interpolated (see Methods)

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TABLE 5

Coefficients from multivariate models relating standardized conditional weight scores to adult fat and fat-free mass (SD units)[a]

	Males					Females				
	Fat mass		Fat-free mass			Fat mass		Fat-free mass		
	β	95%CI	β	95%CI	p-value[b]	β	95%CI	β	95%CI	p-value[b]
Guatemala										
Birth	0.12	(−0.07, 0.30)	0.43	(0.27, 0.59)	0.0001	0.27	(0.06, 0.47)	0.37	(0.18, 0.56)	0.1
12m	0.17	(−0.02, 0.37)	0.26	(0.09, 0.42)	0.30	0.15	(−0.06, 0.36)	0.33	(0.14, 0.52)	0.007
24m	0.09	(−0.09, 0.27)	0.28	(0.13, 0.43)	0.01	0.17	(−0.04, 0.38)	0.24	(0.05, 0.43)	0.28
Mid-childhood	0.15	(−0.05, 0.34)	0.21	(0.05, 0.38)	0.40	0.10	(−0.13, 0.32)	0.16	(−0.05, 0.36)	0.37
India										
Birth	0.13	(0.06, 0.21)	0.20	(0.13, 0.27)	0.02	0.22	(0.13, 0.31)	0.28	(0.20, 0.36)	0.04
12m	0.27	(0.20, 0.35)	0.40	(0.33, 0.47)	0.0001	0.28	(0.19, 0.37)	0.36	(0.28, 0.45)	0.006
24m	0.20	(0.13, 0.27)	0.23	(0.15, 0.30)	0.35	0.13	(0.04, 0.22)	0.23	(0.15, 0.31)	0.0005
Mid-childhood	0.24	(0.17, 0.32)	0.26	(0.19, 0.33)	0.59	0.17	(0.08, 0.26)	0.20	(0.11, 0.28)	0.40
Philippines										
Birth	0.08	(0.03, 0.13)	0.21	(0.16, 0.26)	0.0001	0.17	(0.12, 0.23)	0.28	(0.22, 0.33)	0.0002
12m	0.39	(0.33, 0.44)	0.49	(0.44, 0.54)	0.0005	0.30	(0.24, 0.36)	0.34	(0.28, 0.40)	0.16
24m	0.13	(0.07, 0.18)	0.22	(0.17, 0.27)	0.002	0.09	(0.02, 0.15)	0.13	(0.08, 0.19)	0.11
Mid-childhood[c]	0.43	(0.37, 0.48)	0.48	(0.43, 0.52)	0.09	0.49	(0.43, 0.55)	0.49	(0.44, 0.54)	0.91
South Africa										
Birth	0.21	(0.07, 0.36)	0.31	(0.18, 0.43)	0.31	0.07	(−0.07, 0.21)	0.39	(0.28, 0.50)	0.0001
12m	0.21	(0.05, 0.36)	0.35	(0.22, 0.49)	0.12	0.43	(0.28, 0.57)	0.46	(0.34, 0.57)	0.74
24m	0.10	(−0.05, 0.24)	0.13	(0.01, 0.26)	0.70	0.07	(−0.07, 0.21)	0.29	(0.18, 0.40)	0.006
Mid-childhood[c]	0.26	(0.12, 0.41)	0.44	(0.32, 0.56)	0.05	0.36	(0.21, 0.51)	0.39	(0.27, 0.50)	0.74
Brazil										
Birth	0.17	(0.09, 0.26)	0.26	(0.18, 0.34)	0.003					
12m	0.27	(0.18, 0.35)	0.29	(0.20, 0.37)	0.49					
24m	0.26	(0.18, 0.35)	0.31	(0.22, 0.39)	0.15					
Mid-childhood	0.39	(0.30, 0.47)	0.35	(0.27to 0.43)	0.25					

[a] adjusted for age and in females also for parity

[b] significance of difference in regression coefficients predicting fat-free and fat mass evaluated using multivariate regression

[c] interpolated (see Methods)

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TABLE 6

Coefficients from regression models relating standardized conditional weight scores to adult percent body fat[a]

	Males			Females		
	β	**95% CI**	**p**	***β***	**95% CI**	**p**
Guatemala						
Birth	0.01	(−1.13, 1.16)	0.981	1.46	(0.21, 2.70)	0.0220
12m	0.90	(−0.30, 2.10)	0.14	0.59	(−0.69, 1.88)	0.3590
24m	0.17	(−0.96, 1.29)	0.772	0.76	(−0.50, 2.02)	0.2350
Mid-childhood	1.00	(−0.20, 2.21)	0.102	0.51	(−0.84, 1.86)	0.4580
R^2		0.05			0.14	
India						
Birth	0.45	(0.03, 0.88)	0.0370	1.04	(0.39, 1.68)	0.0020
12m	0.88	(0.45, 1.31)	0.0001	1.58	(0.91, 2.24)	0.0001
24m	0.82	(0.39, 1.26)	0.0001	0.49	(−0.16, 1.13)	0.1370
Mid-childhood	0.99	(0.56, 1.42)	0.0001	0.90	(0.23, 1.56)	0.0080
R^2		0.22			0.15	
Philippines						
Birth	0.16	(−0.14, 0.47)	0.2940	0.31	(−0.01, 0.64)	0.0560
12m	1.46	(1.13, 1.79)	0.0001	0.99	(0.65, 1.34)	0.0001
24m	0.36	(0.04, 0.68)	0.0260	0.20	(−0.14, 0.54)	0.2600
Mid-childhood	1.65	(1.34,1.95)	0.0001	1.57	(1.25,1.90)	0.0001
R^2		0.18			0.15	
South Africa						
Birth	1.49	(0.22, 2.75)	0.021	−0.55	(−1.63, 0.53)	0.3160
12m	1.17	(−0.16, 2.51)	0.085	2.19	(1.08, 3.30)	0.0001
24m	0.67	(−0.59, 1.93)	0.296	−0.29	(−1.35, 0.78)	0.5950
Mid-childhood	1.64	(0.39, 2.88)	0.01	1.92	(0.80, 3.04)	0.0001
R^2		0.10			0.18	
Brazil						
Birth	0.40	(0.04, 0.75)	0.0290			
12m	0.96	(0.59, 1.33)	0.0001			

	Males			Females		
	β	95% CI	p	β	95% CI	p
24m	0.81	(0.44, 1.18)	0.0001			
Mid-childhood	1.25	(0.90, 1.60)	0.0001			
R^2		0.22				

[a] adjusted for age and in females also for parity,

[b] interpolated (see Methods)

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