Birth Size and Later Central Obesity Among Adolescent Girls of Asian, White, and Mixed Ethnicities

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Abstract

Birth size has important implications for health and disease in adulthood. This study examined the association of birth size with central body fat distribution in late adolescence. Data were from a cross-sectional survey of adolescent girls (N=143, 13-18y) of Asian, White and Mixed Asian-white ethnicity collected in 2005-2007 in Hawai'i, USA. Central body fat distribution was assessed with dual-energy x-ray absorptiometry and birth size from birth certificates and parent recall. Food diaries (3-day) were used to determine energy intake and metabolic equivalents of energy expenditure. The proportion of Asian ancestry was determined by questions and anthropometry was performed. T-tests compared groups, and multiple regression examined predictors of central body fat distribution, adjusting for potential confounders. Asian girls had a lower mean weight and gestational age at birth than White girls, and a lower mean dietary fat intake in adolescence. Girls of Asian and Mixed Asian-white ancestry had a more body fat distribution than White girls. Lower birth weight was associated with greater central body fat distribution (0.1 or 10% higher central body fat distribution for every 10 grams lower birth weight), after adjusting for age, ancestry, physical activity, energy intake, and bi-iliac breadth, and gestational age. Further adjusting for birth length attenuated the birth weight effect, and shorter birth length was the significant predictor of central body fat distribution. (0.1 or 10% higher central body fat distribution for every 0.01mm shorter length). If confirmed, these findings would suggest that linear growth may be more relevant to metabolic programming than growth in mass.

Keywords

birth size, ethnicity, body fat, adolescence, body composition

Introduction

Health consequences of obesity range from increased risk of premature death due to serious chronic conditions such as Type 2 diabetes, coronary heart disease (CHD), hypertension, stroke, and certain cancers. Birth size has been found to have important implications for health and disease in adulthood. According to the Barker's "thrifty phenotype" hypothesis, chronic disorders, such as hypertension, insulin resistance and obesity in adult life originate from inadequate intrauterine growth, followed by excessive energy intake after birth.[1,2] Fetal development affects biological programming whereby disease risk results from a mismatch between the exposure of the fetus and the environment after birth.

For example, if a fetus is exposed to malnourishment "in utero," it may be programmed in expectation of a postnatal environment higher metabolic efficiency and lipid storage. When exposed to nutritional abundance in postnatal life, this greater metabolic efficiency leads to obesity and related diseases. Birth size is an indicator of fetal response to the in utero nutritional environment.[3] Indeed, birth weight has been inversely associated with increased risk for Type 2 Diabetes in adulthood.[4] Obesity and central body fat distribution is associated with metabolic risk factors, especially among Asians. In fact, new guidelines for "obesity disease" in Japan defined obesity as a BMI$\geq$25; and the greatest worldwide increase in adult diabetes is projected to occur in Asian populations.[5] Asian-Americans relative to Whites are predisposed to central body fat or trunkal body fat distribution (upper body fat or "Apple" shape). However, the causes of obesity have been less studied in Asians than in Whites, especially during adolescence. The third US National Health and Nutrition Examination Survey (NHANES III) examined adiposity distribution in relation to birth weight among White (n=759), Black (n=916) and Hispanic (n=813) children, aged 5-11.[6] Birth weight was negatively associated with subscapular skinfold thickness and central adiposity (trunkal fat mass as measured by dual-energy x-ray absorptiometry [DXA]). Birth weight was also inversely associated with iliac skinfold thickness in Blacks and Hispanics ($P<.01$), and with sum of four skinfolds in Blacks ($P<.05$). Data were not provided for birth length for Asians in Hawai‘i, or in NHANES III (or previous NHANES surveys). Birth weight adjusted for gestational age was found to be inversely associated with DXA trunk fat mass/total body fat mass in a study of 107 adolescents of African-American, Hispanic, Asian/Other and White ethnicities in New York.[7] Data are limited on birth length. One study found both low and high birth length to be associated with obesity assessed by BMI.[8] No studies were identified that examined the influence of birth length on central body fat distribution, in adolescence or adulthood, or in Asian populations. In this study we examine the relationship of birth length and Mixed Asian/White ethnic ancestry with central body fat distribution in 13-18 year old adolescent girls.

Methods

Population, Design and Recruitment

This study presents data collected in 2005-2007 on Asian, White and Mixed Asian/White girls from the Female Adolescent Maturation (FAM) Study 3 (N=143, aged 13-18). Subjects were recruited from the Kaiser Permanente Health Maintenance Organization membership living on the island of Oahu. The target population was healthy girls of Asian and White ancestry. The overall goal of the FAM Studies was to determine past and current lifestyle patterns for optimal bone growth and for reduced cancer risk factors, such as early puberty and higher central adiposity. The study was approved by the University of Hawai‘i Committee on Human Studies, Hawai‘i Pacific Health Review Board, and the Kaiser Permanente Institutional Review Board.

Measurements

Ethnic Ancestry

We used the BLEND methodology, developed for the FAM studies, to characterize admixed ancestries.[9] We asked parents/

guardians to provide every race/ancestry of the biologic parents of the subject in percent format. Each girl's ancestry was derived from the sum of her mother's and father's reported ancestries. For example, if a girl's father was 50% Asian and 50% White, while her mother was 25% Asian and 75% White, the girls' race/ancestry was calculated at 37.5% Asian and 62.5% White. Asian ancestries included Japanese, Korean, Chinese, Filipino, Indian, Thai, and Vietnamese, as specified in the US Office of Management and Budget (OMB) directive.[10]

Food Intake Assessment

A 3-day food record was collected at each study visit and included two weekdays (Thursday and Friday) and one weekend day (Saturday). A measuring cup, spoon, and ruled paper were provided to help subjects estimate quantities of food items eaten, as well as dietary supplements. A food record collection form was sent to eligible participants for completion prior to their scheduled study visit. At the visit, the food record was probed for clarity and completion using food models. The food record data were processed and individual intake of nutrients was estimated by the Nutrient Support Shared Resource Core at the University of Hawai'i Cancer Center using its comprehensive food composition database which contains national, local and ethnic foods.[11]

Physical Activity Assessment

Participants completed a physical activity questionnaire, developed for adolescents, at each study visit.[12] For each activity they took part in more than ten times in the past year, participants were asked how many months/year, how many days/week and how many minutes/day they spent doing that particular activity, which was then converted to average number of hours/week. The metabolic equivalent (MET) values for all activities were calculated for the specified duration (MET of each activity x duration of each activity). The sum of all MET values per week was used as a proxy measure of activity energy expenditure in the past year.

Dual Energy X-Ray Absorptiometry (DXA) Assessment of Body Fat

We used DXA (GE Lunar Prodigy) to measure total body fat mass (grams) and percent body fat. We calculated a measure of central body fat distribution, trunk-to-periphery fat ratio (TPFR) as fat mass in the trunk over the sum of the fat mass in the arms and legs. A certified radiographic technician trained by the GE Lunar Corporation operated the DXA using standard protocols. Manufacturer quality control procedures were performed on a routine basis, and a manufacturer phantom was measured for calibration. Participants with a positive pregnancy test (n = 1) did not undergo the DXA exam.

Anthropometric Assessment

Anthropometric measures were taken during the visit to the University of Hawai'i Clinical Research Center. Anthropometric measurements included weight, height, skinfold thicknesses, and body breadths. Weight was measured with a digital scale (Seca, Hanover MD) in pounds, and converted to kg for analyses. Height was measured in cm using a digital stadiometer (Measurement Concepts, North Bend WA). Skinfold measurements were taken at the subscapular and triceps sites using a Lange Skinfold Caliper from Beta Technology Incorporated (Cambridge, Maryland).

Circumferences (arm, abdomen, buttocks) and ulna length were measured with an inextensible measuring tape (Rollfix, Hoechst. Mass, Germany). Bi-iliac and biacromial breadth were measured with a Lafayette Caliper. Each measurement was taken at least twice; a third measurement was taken if the two measures differed by two-tenths of a unit or more, with the average of the two closest values used in the analysis.

Tanner Pubertal Stage of Maturation

Tanner breast and pubertal stages were assessed in a clinical examination by trained and standardized medical personnel.[13]

Birth Characteristics

Birth weight and gestational age were obtained preferentially from birth certificates and when the birth certificate information was missing, recalled values were used. As a result, birth weight and gestational age were obtained from the girl's birth certificate for 76% of FAM participants or by parent's recall for the remaining 24% of the participants. Birth length was obtained only by parent's recall. The Spearman correlation coefficient for birth data from recall and birth certificates was 0.95 for birth weight and 0.7 for gestational age. A paired t-test of difference in means of birth weights from birth certificates and self-report showed a non-significant 10g (174.9 SD) difference ($t = 0.55$, $P = .58$, $n = 102$). One implausible birth length value (of 88.9 cm) was dropped from analyses.

Data Entry, Cleaning, and Statistical Analysis

All data were double entered using a Fox Pro database. Two entries were compared and any data that did not match were corrected using the original hard copy of the data. The first level of data cleaning was done to check for duplicates. The second level of cleaning was done to check for missing entries. A third level of cleaning was done to check for outliers, by calculating the mean, maximum and minimum values of every continuous variable and frequency tables for categorical data. SAS version 9.1.3 was used for all analyses. A General Linear Model (GLM) for univariate analysis of variance (ANOVA) was used to test the differences between the means for White, Asian, and Mixed Asian/White participants. The *P*-values were adjusted for Tukey's Honest Significant Difference method, which allows for all possible pair wise tests. Residual analyses were done to check the adequacy of a fitted multiple linear regression model; the residuals had a distribution with moments similar to a normal distribution, with only moderate skewness (0.34), virtually no kurtosis (coefficient of kurtosis -3 = -0.01), and no obvious outliers. Multiple linear regression based on ordinary least squares estimation was used where

TPFR was regressed on birth weight (reflecting fetal growth in mass) and the same covariates considered in our previous analyses,[14] including age, ancestry, physical activity, energy intake, and bi-iliac breadth (indicator of pubertal maturation in pelvic size). In the current analysis, the girls are older and have completed most of their growth. Models were run with and without further adjustments for gestational age and birth length (to account for early fetal linear growth). Interaction of birth weight and ethnicity was tested and was not significant.

Results

Ethnic Differences

There were 41 (100%) Asians, 31 (100%) Whites and 72 Mixed Asian/White girls. The 72 Asian/White Mixed girls had a mean proportion of Asian of 0.51±0.16 (range of 0.25±0.24) and a mean proportion White of 0.49±0.16 (range of 0.06±0.75). The girls were tested for ethnic differences in anthropometry, DXA, diet, physical activity, and birth measures for differences between the ethnic groups (Table 1). Girls were approximately 15.5 years old; age did not vary by ethnic group. Asian girls were smaller than either White of Mixed Asian/White girls in various anthropometric dimensions (weight, height, waist circumference, hip circumference, biacromial breadth, biiliac breadth, biceps skinfold thickness, calf skinfold thickness, total fat mass, peripheral fat mass), but similar in several anthropometric measure of body fat: subscapular skinfold thickness, triceps skinfold thickness, biiliac skinfold thickness, and trunk to periphery fat mass ratio compared to the other two groups. Birth weight was significantly greater among Whites, compared to Mixed Asian/White and Asians (by an average of about 400g), and gestational age was also greater (by about one week. There was no significant difference among ethnic groups in birth length or ponderal index (g/m^3). Asian girls were at an earlier Tanner pubic hair stage than either White or Mixed Asian/White girls, about one half stage earlier, on average. Asian girls had lower dietary fat intakes compared to Whites (by about 6g/day), and lower dietary saturated fat intake compared to Mixed Asian/White girls (by about 4g/day). There were no ethnic differences in energy intake or physical activity level.

Birth Size and Central Body Fat Distribution

A model was built to incorporate known influences on central body fat distribution (TPFR), in addition to the ethnic and birth size variables of interest. Birth weight was introduced to models first, followed by birth length, and then both variables were examined in the same model. The association between Asian ancestry and TPFR (measured by DXA) was not significant (P=.08), adjusting for physical activity, energy intake, bi-iliac breadth, and birth weight. Birth weight was significantly inversely associated with TPFR (-0.096±0.032, P=.0027, adjusting for age, Asian ethnicity and bi-iliac breadth). Adjusting for Tanner pubic hair stage instead of biiliac breadth, as an indicator of maturity, birth weight was also inversely and significantly associated with TPFR (result not shown). Birth weight remained inversely associated with TPFR after adjusting for gestational age and other previously mentioned covariates in the model (birth weight: regression coefficient=-0.099, P=.005; gestational age: regression coefficient=0.007, P=.40). In the final, full model (with birth length added), birth weight was no longer significantly associated with TPFR, after adjusting for birth length (birth weight: regression coefficient=-0.0339, P=.36, Table 2). Birth length, was significantly associated with TPFR (regression coefficient=-0.012, P=.04) Bi-iliac breadth was a highly significant positive predictor of TPFR, controlling for age, ethnicity, physical activity, energy intake, birth weight, and birth length.

Discussion

In this study of an Asian/White ethnic population, smaller birth size models (weight or length) were both associated with greater central adiposity, and ethnicity was not significant. In the full regression model that included both birth weight and length simultaneously, only birth length remained significant. Bi-iliac breadth was another strong indicator of central adiposity. Thus, factors limiting linear skeletal growth may be especially indicative of risk for future central body fat distribution.

This study contributes novel data on the relationship of birth length with later obesity (in adolescence), which is extremely limited in the literature. Low birth weight has been found important to predict later catch up growth and to be inversely associated with central vs peripheral adiposity (as measured by skinfold thicknesses) in Black and Hispanic US children (aged 5 to 11), to a greater degree than in White children.[6] Childhood and adolescent overweight and obesity have been found in a recent systematic review to significantly increase risk of premature mortality and cardiometabolic morbidity (diabetes, hypertension, ischaemic heart disease, and stroke; hazard ratios ranging from 1.1–5.1) and later disability pension, asthma, and polycystic ovary syndrome symptoms.[15] Both low and high birth weights have been associated with higher DXA fat mass in a cross-sectional study of body composition among 9-18 year olds of African-American, Hispanic, Asian/Other, and White children who were participants in the Pediatric Rosetta Study in New York (1995–2000).[7] Controlling for current weight and Tanner stage, the New York study found that higher birth weight was associated with higher fat mass and percent body fat, while a low birth weight was associated with higher central body fat distribution measured by trunk fat mass adjusted for total fat mass. In our study, the relationship between birth weight and central body fat distribution was inverse and linear. Additionally, our analysis controlled for more potentially confounding covariates (age, bi-iliac breadth, energy intake, and physical activity level) than most previous studies. Our results suggest that the relationship of smaller birth size with more central body fat distribution reflects fetal influences on body composition and metabolism on adolescent body fat distribution.

In previous cross-sectional examination of 107 Asian and white adolescent girls aged 11-16 in this population, we showed that DXA trunk-to-periphery fat ratio (TPFR), taken as a measure of central adiposity, was associated with Asian ancestry, lower

Table 1. Mean ± SE Anthropometric Variables, Physical Activity and Dietary Intake for FAM3 Study Participants, (age 13-18) by Race/Ethnic Group, 2005-2007.			
	100% Asian (n=41) Mean ± SE	**Mixed[a] (n=72) Mean ± SE**	**100% White (n=31) Mean ± SE**
Anthropometry			
Age (y)	15.6 ± 0.3	15.8 ± 0.2	16.7 ± 0.3
Weight (kg)	50.4 ± 1.9[b]	57.6 ± 1.4[c]	59.6 ± 2.2
Height (cm)	158.0± 0.9[b]	160.9 ± 0.7[c]	163.8 ± 1.1
Bi-acromial breadth (cm)	35.4 ± 0.3	36.3 ± 0.2[c]	36.1 ± 0.3
Bi-iliac breadth (cm	26.9 ± 0.4	28.2 ± 0.3[c]	28.0 ± 0.4
Waist circumference (cm)	64.6 ± 1.3[b]	69.5 ± 1.0[c]	69.7 ± 1.5
Hip circumference (cm)	90.2± 1.4[b]	95.5 ± 1.1[c]	96.7 ± 1.6
Subscapular skinfold (mm)	14.0 ± 1.1	16.5 ± 0.8	16.0± 1.2
Triceps skinfold (mm)	17.6 ± 1.00	19.3 ± 0.8	20.8 ± 1.1
Biceps skinfold (mm)	9.7 ± 0.8[b]	12.3 ± 0.6[c]	13.3 ± 0.9
Iliac skinfold (mm)	19.4 ± 1.6	22.9 ± 1.2	22.6 ± 1.8
Calf skinfold (mm)	16.9 ± 1.1[b]	20.2 ± 0.8[c]	22.0 ± 1.2
Pubic Tanner Stages (I-V)	3.8 ± 0.1[b] (n=35)	4.1 ± 0.1[c] (n=58)	4.4 ± 0.1 (n=23)
DXA measures[d]			
DXA total fat mass (kg)	13.9 ± 1.3[b]	18.3 ± 1.0[c]	19.0 ± 1.5
DXA trunk fat mass (kg)	6.7 ± 0.7	9.0± 0.6[c]	9.1 ± 0.8
DXA peripheral fat mass (kg)	6.6 ± 0.6[b]	8.6 ± 0.5[c]	9.3 ± 0.7
DXA trunk -periphery fat ratio (TPFR)	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Physical activity[e] and Dietary intake[f] (3-day food record)			
Physical activity (MET hr/wk)	95.2 ± 9.2	88.7 ± 6.6	115.2± 10.3
Energy intake (kj/d)	7247 ± 320	7861 ± 238	6829 ± 372
Protein (g/d)	64.6 ± 3.3	69.8 ± 2.5	60.3 ± 3.8
Fat (g/d)	62.1 ± 3.8b	73.4 ± 2.8	64.8 ± 4.4
Carbohydrate (g/d)	232.0 ± 11.0	238.5 ± 8.2	206.5 ± 12.7
Saturated fat (g/d)	20.1 ± 1.4	24.7 ± 1.1c	23.0± 1.6
Birth measures			
Gestational age (wks)	39.4 ± 0.3b(n=40)	39.6 ± 0.2c (n=71)	40.7 ± 0.3
Birth weight (kg)	3.1 ± 0.1b (n=41)	3.2 ± 0.1b (n=71)	3.5 ± 0.1 (n=31)
Birth length (cm)	49.6 ± 0.6b(n=29)	50.8 ± 0.4 (n=62)	51.6 ± 0.6 (n=25)
Ponderal Index (kg/m^3)	2.5 ± 0.1 (n=29)	2.5 ± 0.1 (n=62)	2.6 ± 0.1 (n=25)

[a]Mean proportion Asian 0.51 + 0.16 (range of 0.25 + 0.24); mean proportion White 0.49 + 0.16 (range of 0.06 + 0.75)
[b]Significantly different from White, *P* (<.01) values are adjusted for multiple comparisons using Tukeys' method (26)
[c]Significantly different from Asian, *P* (<.01) values are adjusted for multiple comparisons using Tukeys' method
[d]n = 141, missing information on two girls for DXA scan: Mixed Asian/White, n = 69
[e]Physical activity: Asian, n = 36; Mixed Asian/White, n = 71; White, n = 29
[f]Dietary Intake: Asian, n = 39; Mixed Asian/White, n = 70; White, n = 29

birth weight, and greater bi-iliac breadth.[9] Asian ethnicity was not as strong a predictor of central body fat distribution in this study of girls aged 13-18 ($P = .08$), as it was in the younger age group (9-16) ($P = .001$).[14, 15] This may be due to the differential timing of maturation between the ethnic groups, as Asians were less mature than Whites or Asian/White Mixed girls at the time of measurement in late adolescence. Bi-iliac breadth, an indicator of pelvic size, which typically matures late in adolescence, remained a highly significant predictor of central body fat distribution, as it was in our previous study with the younger age group (9-16) of girls.[9] Factors influencing shape and size of the skeleton (ie, bi-iliac breadth) are worthy of further study as potential moderators of central body fat distribution.

Asian girls were at an earlier pubic hair maturation stage compared to White girls. Biro, et al,[16] described two pathways of onset of pubertal maturation, the thelarche pathway (initiated by areolar and breast development) and the adrenarche pathway (initiated by pubic hair development). The thelarcheal pathway

Table 2. Final Models of Predictors of DXA Trunk-to-Periphery Fat Ratio (TPFR) Among Asian, White, and Mixed Asian/White Participants in the FAM3 Study (Multiple Linear Regression), 2005-2007.

	Model 1 (n=133)			Model 2 (n=110)*		
Variables	Regression Coeff	SE	P	Regression Coeff	SE	P
Intercept	0.506	0.232		0.897	0.325	
Age (y)	0.001	0.009	0.90	0.002	0.011	0.88
Asian ancestry (%)	0.071	0.041	0.08	0.081	0.046	0.08
Physical activity (METs, hrs/wk x 10000)	-0.136	0.262	0.60	-0.111	0.286	0.70
Energy intake (kj/d x 1000)	0.001	0.007	0.86	0.003	0.007	0.72
Bi-iliac breadth (cm)	0.026	0.006	<.0001	0.026	0.007	0.0002
Birth weight (kg)	-0.085	0.031	0.01	-0.034	0.037	0.36
Birth length (cm)				-0.012	0.005	0.04

*Missing data: age, Asian ancestry, bi-iliac breadth and birth weight missing for 2 girls; physical activity missing for 9; energy intake missing for 7 and birth length missing for 29

was more strongly associated with overweight (including higher waist-to-height ratio, analogous to the TPFR), and with earlier menarche, in White girls.[17] Girls with a lower pubic hair stage (more of the Asian girls), may be experiencing a thelarcheal pathway of maturation, and a greater tendency to central body fat distribution. For example,[17] a one unit of increase in BMI Z score has been found associated with earlier breast bud appearance (earlier occurrence of Tanner breast stage 2), by a median of 5.6 months. Thus, as the study girls mature further, an Asian tendency toward central body fat distribution may become more pronounced.

Our results are consistent with a number of epidemiologic studies that have shown an association between perinatal characteristics and adult chronic diseases, including an inverse association between birth weight and subsequent risk of Type 2 diabetes.[18-21] Our findings also support the hypothesis proposed by Barker and others[1,22,23] that metabolic programming occurs during fetal and early postnatal periods, persists throughout growth, and ultimately affects the risk of overt metabolic disorders in adulthood. The finding that birth length may be more important than birth weight would suggest that early gestational linear growth would be even more relevant to metabolic programming than later gestational growth in mass (when most of the weight is accrued). Our study further suggests that these health consequences in adulthood may be mediated through the development of central body fat distribution in adolescence, an established risk factor of various chronic diseases in adults.[3]

Our study is limited by a lack of longitudinal measures, other than maternally recalled birth data. Also, we did not have birth certificate birth length data to validate reported birth length measures. However, other research has shown excellent maternal recall of birth length data, with no significant difference from medical records.[24] The Asian ethnic group is a highly diverse group composed of Oriental East Asians, Filipinos, Southeast Asians, and South Asians. These groups have different genetic ancestries and have population variability in disease rates. Within the Asian ethnic group South Asians have higher body fat mass and Chinese have lower body fat mass.[25] Nonetheless, the ethnic group shows a number of differences from White populations that warrant further examination. Further, we demonstrate novel differences between Mixed Asian/White populations and the Asian and White populations. While values tend to fall between the two groups, as expected, Mixed Asian/White body size more closely resembles the larger White values. Further, the dietary data suggest higher intake among Mixed Asian/Whites than either single ethnic group. We hypothesize that the Mixed Asian/White group consumes foods for both cultural backgrounds, especially celebratory foods that are of higher fat and calorie value, resulting in overall higher dietary fat intake.

In conclusion, our data show that smaller birth size, especially smaller birth length, adjusted for gestational age and adolescent growth parameters, predicts central body fat distribution of girls in late adolescence. The study suggests that low birth length, in addition to low birth weight, should be further examined for use as a risk indicator for subsequent abdominal obesity and associated health risks.

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Conflict of Interest

The authors report no conflict of interest.

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