“Child height and the risk of young-adult obesity”

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BY

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Abstract

BACKGROUND: Childhood obesity is a major risk factor for adult obesity. Our research aim is to evaluate whether the association of child height and BMI alters the longitudinal tracking from childhood into young adulthood of clinically recommended categories of overweight status.

METHODS: A multicenter prospective cohort study of subjects assessed in both 3rd grade and 12th grade, n = 2,802. Main exposures were CDC childhood body mass index (BMI) categories and height quartiles from 3rd grade measurements. Main outcome measure was CDC adult BMI categories from 12th grade measurements. Associations between childhood height quartiles, childhood BMI categories and adult BMI categories were assessed using chi-square tests and logistic regression models.

RESULTS: Overall, 79% of overweight children remained overweight as young adults. Among children who were overweight or obese, the probability of becoming an overweight or obese young adult was 85% for children in the top quartile of height and 67% for children in the bottom quartile of height ($p = 0.007$). Among children who were normal weight, the probability of becoming an overweight or obese young adult was 25% for children in the top height quartile v. 17% for children in the bottom height quartile ($p = 0.003$).

CONCLUSIONS: When clinicians classify children by BMI categories and counsel about the risk for future obesity, they should recognize that greater height is not protective. Rather, greater height may be a marker for increased risk of adult overweight and obesity.

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Background of thesis research question:

During my clinical time as a Family Physician in Lawrence, Massachusetts in the mid-to-late 1990's, I noticed that overweight and obese children tended to be taller than the reference standards for their age and gender. This was particularly odd as (1) the reference standards were from a population of primarily Non-Hispanic whites, (2) the clinic cared for a population that was primarily of Hispanic/Latino ethnicity, and (3) Hispanics/Latinos tend to be shorter than Non-Hispanic whites. I was taught that these overweight and tall children would follow along their growth curves, and that the goal for the clinician was to have the child's weight stabilize and then the obesity would disappear. Following these children over the years, it was apparent that these tall children did not have continued growth in stature with normalization of their body composition. Rather, they tended to have a deceleration in height growth, a continuation of weight gain and a worsening of obesity.

These observations left me with some initial research questions, such as the following:

(1) Was it true that overweight and obese youth were also of above average height?

(2) If so, are overweight and obese adults taller than average?

(1) Was it true that overweight youth were also of above average height?

As summarized by Wolff in 1954, studies from the 1930's began documenting that obese children were taller than their peers[1, 2] . More recently, a cross-sectional analysis of children and adolescents in the Bogalusa Heart Study found a positive association between height and BMI in children under 10 years old, such that the shorter children (height-for-age < 20th percentile) had only a 1-2% prevalence of obesity (BMI ≥ 95th%), whereas those who were taller (height for age > 80th percentile) had a prevalence of obesity between 11% and 26%[3]. Our previous analysis of 2,802 participants from the Child and Adolescent Trial for Cardiovascular Health (CATCH), with measured heights and weights in both 3rd grade (mean age 8.8 years old) and 12th grade (mean age 18.3 years old), also documented a positive association between height and obesity in the 3rd graders[4].

(2) Are overweight and obese adults taller than average? The clinical measurement for obesity is body mass index, BMI (defined as weight (kg)/height $(m)^2$). Quetelet developed the measure after studying adults in the early part of the 19th century with the tenets that it is both associated with adiposity and independent of height[5]. Future studies have generally confirmed this lack of association of BMI and height in adults. However, of particular interest, when an association between height and obesity in adults has been found, it has generally been a negative one, i.e. the opposite of what has been found in children[6]. A commentary discussing these conflicting associations was the lead editorial in the British Journal of Nutrition and listed in the appendix of this thesis[7].

<u>Thesis question: If overweight and obese children do not remain taller with age, then does their increased childhood height alter the prediction of future, adult obesity?</u>

It is well established that childhood obesity is a major risk factor for adult obesity[8, 9]. As a clinician trying to properly curtail the epidemic of adult obesity, I was interested in whether the conflicting associations between height and obesity in children compared with adults impacted the longitudinal tracking of obesity. This question led to the research publication that is the focus of this thesis, “Child Height and the Risk of Young-Adult Obesity”[10]. This manuscript was published in the American Journal of Preventive Medicine in January 2010. Permission has been granted by Elsevier publishing (see Appendix C).

REFERENCES for Introduction

1. Wolff OH. Obesity in childhood; a study of the birth weight, the height, and the onset of puberty. *Q J Med*. 1955;24(0033-5622; 94):109-123.

2. Bruch H. Obesity in childhood: Physical growth and development of obese children. *Am J Dis Child*. 1939;58(3):457-484.

3. Freedman DS, Khan LK, Serdula MK, Dietz WH, Srinivasan SR, Berenson GS. Inter-relationships among childhood BMI, childhood height, and adult obesity: The bogalusa heart study. *Int J Obes Relat Metab Disord*. 2004;28(0307-0565; 1):10-16.

4. Stovitz SD, Pereira MA, Vazquez G, Lytle LA, Himes JH. The interaction of childhood height and childhood BMI in the prediction of young adult BMI. *Obesity (Silver Spring)*. 2008;16(1930-7381; 10):2336-2341.

5. Heymsfield SB, Gallagher D, Mayer L, Beetsch J, Pietrobelli A. Scaling of human body composition to stature: New insights into body mass index. *Am J Clin Nutr*. 2007;86(1):82-91.

6. Bosy-Westphal A, Plachta-Danielzik S, Dorhofer RP, Muller MJ. Short stature and obesity: Positive association in adults but inverse association in children and adolescents. *Br J Nutr*. 2009;102(3):453-461.

7. Stovitz SD. Shorter adults, yet taller children: What's up? *Br J Nutr*. 2009;102(3):329-330.

8. Parsons TJ, Power C, Logan S, Summerbell CD. Childhood predictors of adult obesity: A systematic review. *Int J Obes Relat Metab Disord*. 1999;23 Suppl 8(0307-0565):S1-107.

9. Whitlock EP, Williams SB, Gold R, Smith PR, Shipman SA. Screening and interventions for childhood overweight: A summary of evidence for the US preventive services task force. *Pediatrics*. 2005;116(1098-4275; 1):e125-e144.

10. Stovitz SD, Hannan PJ, Lytle LA, Demerath EW, Pereira MA, Himes JH. Child height and the risk of young-adult obesity. *Am J Prev Med*. 2010;38(1):74-77.

Title: Child Height and the Risk of Young-Adult Obesity

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INTRODUCTION

For the prevention and treatment of obesity, clinicians are instructed to categorize children according to body mass index (BMI) percentiles, and then counsel(1-3). BMI was derived as an index of adiposity that adjusts a subject's weight for his/her height so there is minimal association between BMI and height. While this has generally been true in adults, in children several studies have noted a positive association between BMI and height(4-8).

We previously analyzed the interrelationship between child height and BMI as a continuous variable and found a statistical interaction in the prediction of young adult BMI(9). In children with a BMI below the 80^{th} percentile the association of child and adult BMI did not differ between children of different heights. However, among children with a BMI above the 80^{th} percentile, those who were taller had significantly higher young adult BMI compared with those who were shorter.

Our current research aim is to evaluate whether the association of child height and BMI alters the longitudinal tracking from childhood into young adulthood of clinically recommended categories of overweight status.

METHODS:

Study population:

Participants are from the Child and Adolescent Trial for Cardiovascular Health (CATCH), a multi-center, cluster-randomized field trial designed to evaluate the effectiveness of school and home-based interventions to reduce cardiovascular risk factors. In Fall 1991, 5,106 third-graders were assessed. As twelfth-graders (Spring 2001), 2,909 were reassessed, of which 2,802 had complete data and were used for this analysis. Details of the original study(10) and this longitudinal cohort are described elsewhere(9).

The intervention and control groups did not differ with respect to weight, height, or BMI at baseline or follow-up. They were therefore merged and analyzed as a single cohort. Furthermore, group assignment was controlled statistically as a fixed effect.

Anthropometry:

Weight and height were measured in 3rd and 12th grades by trained and certified study examiners(11). The mean of two measurements were used for analysis. BMI was calculated as weight (kg)/height (m)-squared.

Exact percentiles for weight, height and BMI for age and gender were calculated relative to the CDC-2000 reference growth charts(12;13). Third-graders were referred to as “children,” with normal weight defined as BMI < 85th percentile, overweight defined as BMI ≥ the 85th percentile and < the 95th percentile, and obesity defined as BMI ≥ 95th percentile(3). Twelfth-graders were referred to as “young adults,” with normal weight defined as BMI < 25, overweight defined as BMI ≥ 25 kg/m^2 and < 30 kg/m^2, and obesity defined as BMI ≥ 30 kg/m^2.

***Statistical Analyses*:**

Cross tabulations of childhood height (quartiles by CDC norms) with weight status (normal, overweight or obese) were constructed, and tested for association by chi-square tests. The predictive values of childhood overweight status for adult overweight status were assessed via logistic regression adjusted for age, gender, race/ethnicity, geographic region and intervention condition. Individual school was included as a random effect. Differences in positive and negative predictive values between strata of childhood height were tested by large-sample t-tests. All analyses used SAS version 9.1(14).

RESULTS

Table 1 shows descriptive data.

Child height was positively associated with both child overweight status ($r = 0.29$, $p < 0.0001$) and adult overweight status ($r = 0.21$, $p < 0.0001$). In young adults, overweight status and height were uncorrelated ($r = -0.005$).

As seen in Table 2, there was a strong association between childhood overweight and adult overweight. Among the 712 children who were overweight or obese in 3rd grade, 566 (79%) remained overweight or obese as young adults. Among the 2090 children who were normal weight in 3rd grade, 1659 (coincidentally, also 79%) remained normal weight as young adults.

Within similar childhood BMI categories, greater childhood height was significantly associated with adult overweight or obesity. We merged the two middle quartiles of child height. Among children who were overweight or obese, those who were also tall had an 85% probability of becoming an overweight or obese young adult (i.e. PPV). Among those children who were short and either overweight or obese, the probability of becoming an overweight or obese adult was significantly lower at 67% ($p = 0.007$). Assessing children who were normal weight, those who were tall had a 75% probability of remaining normal weight as a young adult (i.e. NPV). Among children who were normal weight and short, 83% remained normal weight as a young adult ($p = 0.003$). Adjustment for race/ethnicity, gender, site, school, and location did not materially alter the findings.

DISCUSSION

Consistent with our previous analysis(9), this investigation found a positive association between child height and young adult overweight status among children who had an elevated BMI. Overweight children who were in the tallest quartile had an 18% higher probability of remaining overweight or obese as young adults compared with overweight children who were in the shortest quartile (85% v. 67%, respectively).

The current study has novel findings in children who had normal BMIs. Among children who were normal weight, taller child height was associated with a higher risk of young adult overweight or obesity. Specifically, among those children who were normal weight, 25% who were in the tallest quartile became young adults who were overweight or obese. Only 17% of those who were normal weight and in the shortest quartile became overweight or obese adults. These differences in risk are comparable to differences seen between those with and without accepted obesity-related risk factors, such as ethnicity and geographic location(15;16). Possible explanations for this positive finding in children with normal BMI percentiles in contrast to the null finding in the previous study could be due to different outcome variables (i.e. categorical, BMI ≥ 25, in the current study v. continuous BMI in the previous study) or due to an interaction occurring between child height and BMI in those with a BMI between the 80^{th} and 85^{th} percentiles compared with those with a BMI < 80^{th} percentile.

There are many aspects to our study which make it relevant to clinical and research issues in preventive medicine. We have not found any published study of a larger longitudinal U.S. cohort with measured heights and weights from both childhood and adulthood. We are unaware of any previous analysis evaluating the effect modification of child height on the relationship of child overweight status and the prediction of young adult overweight status.

Our study had limitations. Only 55% of the original cohort was available for the longitudinal analyses. Analysis of the longitudinal cohort suggests that they were generally similar to the original cohort but with a tendency to be female (51% v. 45%) and Non-Hispanic (90% v. 82%).

Overweight children are at high risk for becoming overweight adults(17). When assessing a child who is overweight and also tall, one may hope the child's weight growth will slow, his/her height growth pattern will continue, and his/her BMI will normalize. From this perspective, tallness may be interpreted as protective against future obesity. Our results suggest the opposite. Compared with shorter children; overweight and obese children who were tall were more likely to remain overweight and obese as young adults. In addition, normal weight children who were tall were more likely to become overweight or obese young adults. For the prevention of young adult overweight and obesity, health professionals should recognize that greater childhood height may be a marker for increased risk.

Table 1. Descriptive characteristics of the CATCH cohort with measurements in both 3^{rd} and 12^{th} grades, n = 2802.

Descriptive characteristics of the CATCH cohort with measurements in both 3^{rd} and 12^{th} grades, n = 2,802		
Gender (female %)	51.2	
Race/Ethnicity, n (%)		
Non-Hispanic White	2,070 (74%)	
Non-Hispanic Black	335 (12%)	
Hispanic	290 (10%)	
Other	107 (4%)	
	Children	**Young Adults**
Age in years, Mean (SD)	8.7 (0.45)	18.3 (0.5)
Date of measurement	Fall 1991	Spring 2001
Weight (kg), Mean (SD)	30.9 (6.9)	74.1 (17.5)
Weight percentile*: Mean (SD) Median [25^{th}, 75^{th}%]	59.6 (28.1) 62.3 [37.6, 84.9]	64.1 (28.5) 70.7 [42.5, 89.4]
Height (cm), Mean (SD)	132.5 (6.1)	170.5 (9.4)
Height percentile*: Mean (SD) Median [25^{th}, 75^{th}%]	53.8 (27.5) 55.8 [31.3, 77.1]	53.7 (28.6) 54.5 [29.2, 79.0]
BMI, Mean (SD)	17.5 (2.9)	24.5 (5.3)
BMI percentile*: Mean (SD) Median [25^{th}, 75^{th}%]	59.9 (28.1) 63.3 [37.9, 85.3]	61.9 (29.4) 67.2 [38.7, 88.5]
Overweight and Obese,* n (%)	712 (25.4%)	998 (35.6%)
Obese only,† n (%)	295 (10.5%)	367 (13.1%)

*Overweight for children is a BMI ≥ 85^{th}%ile and for adults is a BMI ≥ 25

†Obese for children is a BMI ≥ 95^{th}%ile and for adults is a BMI ≥ 30

Table 2: Predictive values for the longitudinal tracking of overweight status from childhood into young adulthood, stratified by childhood height.

	Total		Childhood Height Quartile #1 (Shortest)		Childhood Height Quartiles #2 and 3		Childhood Height Quartile #4 (Tallest)	
	Adult-Normal weight* (n = 1,805)	Adult-Overweight or Obese** (n = 997)	Adult-Normal weight* (n = 426)	Adult-Overweight or Obese** (n = 120)	Adult-Normal weight* (n = 995)	Adult-Overweight or Obese** (n = 491)	Adult-Normal weight* (n = 384)	Adult-Overweight or Obese** (n = 386)
Childhood Weight, Normal[†] (n = 2090)	1659 TN	431 FN	408 TN	83 FN	917 TN	239 FN	334 TN	109 FN
Childhood Weight, Overweight or Obese[††] (n = 712)	146 FP	566 TP	18 FP	37 TP	78 FP	252 TP	50 FP	277 TP
Positive Predictive Value	79%		67%		76%		85%[§]	
Negative Predictive Value	79%		83%		79%		75%[‖]	

[†] Childhood normal weight defined as BMI < 85^{th}%ile, [††] Childhood overweight or obese defined as BMI ≥85^{th}%ile.
* Adult normal weight defined as BMI < 25, ** Adult overweight or obese defined as BMI ≥ 25.
TP = True positives, FP = False Positives, FN = False Negatives, and TN = True Negatives
Positive Predictive Value = TP/(TP + FP)
Negative Predictive Value = TN/(FN +TN)
[§]Test of difference in PPV between top and bottom quartiles has p = 0.007.
[‖]Test of difference in NPV between top and bottom quartiles has p = 0.003.

Reference List

(1) Bellizzi MC, Dietz WH. Workshop on childhood obesity: summary of the discussion. Am J Clin Nutr 1999; 70(1):173S-175S.

(2) Dietz WH, Robinson TN. Use of the body mass index (BMI) as a measure of overweight in children and adolescents. J Pediatr 1998; 132(2):191-193.

(3) Barlow SE. Expert committee recommendations regarding the prevention, assessment, and treatment of child and adolescent overweight and obesity: summary report. Pediatrics 2007; 120 Suppl 4:S164-S192.

(4) Freedman DS, Khan LK, Serdula MK, Dietz WH, Srinivasan SR, Berenson GS. Inter-relationships among childhood BMI, childhood height, and adult obesity: the Bogalusa Heart Study. Int J Obes Relat Metab Disord 2004; 28(1):10-16.

(5) Freedman DS, Thornton JC, Mei Z, Wang J, Dietz WH, Pierson RN, Jr. et al. Height and adiposity among children. Obes Res 2004; 12(5):846-853.

(6) He Q, Karlberg J. Bmi in childhood and its association with height gain, timing of puberty, and final height. Pediatr Res 2001; 49(2):244-251.

(7) Bruch H. Obesity in Childhood: Physical growth and development of obese children. Am J Dis Child 1939; 58(3):457-484.

(8) Wolff OH. Obesity in childhood; a study of the birth weight, the height, and the onset of puberty. Q J Med 1955; 24(94):109-123.

(9) Stovitz SD, Pereira MA, Vazquez G, Lytle LA, Himes JH. The interaction of childhood height and childhood BMI in the prediction of young adult BMI. Obesity (Silver Spring) 2008; 16(10):2336-2341.

(10) Perry CL, Stone EJ, Parcel GS, Ellison RC, Nader PR, Webber LS et al. School-based cardiovascular health promotion: the child and adolescent trial for cardiovascular health (CATCH). J Sch Health 1990; 60(8):406-413.

(11) Webber LS, Osganian V, Luepker RV, Feldman HA, Stone EJ, Elder JP et al. Cardiovascular risk factors among third grade children in four regions of the United States. The CATCH Study. Child and Adolescent Trial for Cardiovascular Health. Am J Epidemiol 1995; 141(5):428-439.

(12) Kuczmarski RJ, Ogden CL, Grummer-Strawn LM, Flegal KM, Guo SS, Wei R et al. CDC growth charts: United States. Adv Data 2000;(314):1-27.

(13) A SAS program for the CDC 2000 growth charts. Accessed online on July 14, 2009 at http://www.cdc.gov/nccdphp/dnpa/growthcharts/resources/sas.htm

(14) SAS Institute Inc. SAS Online Doc 9.1.3. 2006. Cary, NC, SAS Institute, Inc.

(15) Ogden CL, Carroll MD, Flegal KM. High body mass index for age among US children and adolescents, 2003-2006. JAMA 2008; 299(20):2401-2405.

(16) Levi J, Segal LM, Gadola E. How obesity policies are failing in America, 2009. A report from The Robert Wood Johnson Foundation. Accessed on July 11, 2009 at http://www.rwfj.org/childhoodobesity/product.jsp?id=45050

(17) Whitlock EP, Williams SB, Gold R, Smith PR, Shipman SA. Screening and interventions for childhood overweight: a summary of evidence for the US Preventive Services Task Force. Pediatrics 2005; 116(1):e125-e144.

Appendix A

The Interaction of Childhood Height and Childhood BMI in the Prediction of Young Adult BMI

Steven D. Stovitz[1], Mark A. Pereira[2], Gabriela Vazquez[2], Leslie A. Lytle[2] and John H. Himes[2]

The purpose of this study was to examine the interaction of childhood height and childhood BMI in the prediction of young adult BMI. The 2,802 subjects in this study were from the Child and Adolescent Trial for Cardiovascular Health (CATCH). The subjects' heights and weights were measured in 3rd grade (mean age 8.7 years) and again in 12th grade (mean age 18.3 years). The associations and interactions between height (cm) and BMI (kg/m^2) were assessed using mixed linear regression models with adult BMI as the dependent variable. We found a significant interaction between childhood height and childhood BMI in the prediction of adult BMI ($P < 0.0001$). Stratification by Centers for Disease Control and Prevention (CDC) reference quintiles revealed that a positive association between childhood height and adult BMI existed only for those subjects in the top quintile of childhood BMI, within whom predicted adult BMI ranged from 27.5 (95% confidence interval = 26.4–28.6) for those in the shortest height quintile to 30.2 (95% confidence interval = 29.7–30.6) for those in the highest height quintile. Among children with high BMI levels, those who were taller, as compared to those who were shorter, had significantly higher young adult BMI levels. This pattern seems primarily due to the positive association of childhood height and childhood BMI. Clinicians should recognize the risk of excess body weight in young adulthood for all children who have a high BMI, and pay special attention to those who are tall, because their childhood height will not protect them from subsequent weight gain and elevated BMI.

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INTRODUCTION

Obesity is now considered a worldwide health epidemic (1). In the United States, the prevention and treatment of obesity is the subject of a recent Surgeon General's report and a major goal for Healthy People 2010 (2,3). Pediatric obesity is a major risk factor for adult obesity (4–10). Accordingly, to control the adult obesity epidemic, it is important to study the growth characteristics of children who are at risk for adult obesity.

Although obesity generally refers to excessive adipose tissue relative to lean mass, the exact definition of excessive has not been standardized. As a clinical measure of obesity to be used in many settings, BMI, defined as weight (in kilograms) divided by height (in meters) squared, has been advocated for use in both children and adults (2,11–16). Studies have consistently found an association between childhood BMI and adult BMI (9,10,17–19). Elevated adult BMI is associated with a variety of adverse health effects (20). Thus, childhood BMI has been advocated as an easily assessed and meaningful marker from which clinicians and researchers should judge a child's risk for excessive adult BMI (10).

The formula for BMI was derived, in part, to adjust body weight for height, with the goal of minimizing the effect of stature on body weight. However, in children, increased height has been found to be positively associated with BMI and adiposity (18,21–23). Given the association of childhood BMI with adult BMI, it follows that childhood height has been associated with both BMI and adiposity in adulthood (18,21,24,25). In adults, there does not appear to be an association between concurrent height and BMI, even in longitudinal cohorts where an association between height and BMI existed in childhood (21,26). Thus, although heavy prepubescent children are generally taller than average children, they tend to become average height as adults. Previous research has called for further investigation into the associations between height and BMI in childhood and adulthood using other cohorts (18,24,26).

The purpose of this study was to evaluate the longitudinal associations of childhood BMI and childhood height to young adult BMI in a geographically diverse US cohort. Our primary goal was to examine the interaction of childhood height and childhood BMI in the prediction of young adult BMI in a large prospective analysis. Our hypothesis was that among children

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with high BMI levels, taller children, as compared with shorter children, would have higher BMI levels in early adulthood.

METHODS AND PROCEDURES

Study population

The subjects from this study come from the Child and Adolescent Trial for Cardiovascular Health (CATCH). CATCH was a multicenter, cluster-randomized field trial aimed at evaluating the effectiveness of an elementary school-based intervention to improve cardiovascular risk factors via diet, physical activity, and smoking prevention. Ninety-six schools near four field centers (the University of California at San Diego, La Jolla; University of Minnesota, Minneapolis; University of Texas at Austin; and Tulane University School of Public Health and Tropical Medicine, New Orleans, LA) were randomized to either intervention (14 schools per site, 56 total) or control (10 per site, 40 total). The details of the original study are described in detail elsewhere (27).

The study originally assessed 5,106 3rd graders during the fall of 1991. In the spring of 2001, 2,909 of the original subjects were reevaluated in 12th grade. Dropouts from the original cohort were those moving out of the area or choosing not to participate in the follow-up survey (n = 1,968), and those who did not return consent forms (n = 229). In addition, 107 had missing data in either the 3rd or 12th grade. The final sample analyzed for this study consisted of 2,802 subjects (55% of the original cohort) followed longitudinally. Compared with those included in this longitudinal analysis, those lost to follow-up were boys (55% vs. 49%), older (mean age 8.8 years vs. 8.7 years), and Hispanic (18% vs. 10%). Those lost to follow-up were of similar weight z-scores, but they were shorter (height z-score = 0.07 vs. 0.14) and had higher BMI z-scores (0.41 vs. 0.34). Among the cohort used in this analysis, the intervention and control groups did not differ with respect to weight, height, or BMI at baseline or follow-up and they were therefore merged and analyzed together as a single cohort. In addition, group assignment was controlled for statistically as a fixed effect in all analyses. The subjects in 12th grade were generally over 18 years of age (mean 18.3 years, s.d. 0.5). For the sake of these analyses, 3rd graders will be referred to as "children" and 12th graders will be "young adults."

Anthropometry

All measurements were taken by certified CATCH examiners who received training in standard protocols annually from the central coordinating center (28). In both the 3rd and 12th grades the subjects were measured after removing their shoes, sweaters, and outerwear. Standing height was measured twice without shoes to the nearest 0.1 cm using a portable stadiometer (Perspective Enterprises, Kalamazoo, MI), and the mean of the two values was used for analysis. Weight was measured twice to the nearest 0.1 kg using balance beam scales (Detecto Medic balance scale; Detecto Scales, Brooklyn, NY), and the mean of the two measurements was used for the analysis. BMI was calculated as weight (in kilograms) divided by height (in meters) squared. Age, gender, and race/ethnicity were recorded for all participants.

Statistical analyses

Sample characteristics for categorical variables (gender, ethnicity, overweight, obesity) were described by distribution in percentage. Exact percentiles for weight, height, and BMI for age and gender were calculated for the Centers for Disease Control and Prevention (CDC) 2000 reference values derived from the US population of the 1960s, 1970s, and 1980s (29,30). For children, overweight was defined the 85th percentile or more and less than the 95th percentile for CDC reference, and obese was defined as more than equal to 95th percentile for CDC reference (31). For adults (those in the 12th grade) overweight was defined as a BMI ≥25 and <30, and obese was defined as a BMI ≥30. Continuous variables (age, weight, height, and BMI) were described by means and standard deviation and by medians and 25th percentile and 75th percentile of the cohort.

The relationships of childhood BMI (kg/m^2) and adult BMI (kg/m^2), and childhood height (cm) and adult BMI (kg/m^2) were graphically displayed using smoothed adjusted means, using a smoothing spline and adjusting for age, gender, site, intervention arm, and ethnicity in a generalized additive model (32). Linear and nonlinear associations of anthropometric variables were assessed using linear mixed models, including age, gender, ethnicity, site, and intervention arm as fixed effects (adjusting for confounding) and school as a random intercept term. School was modeled as a random term to consider the clustering effect arising from the sampling design. Linear associations between the anthropometric variables were tested by including the variable as a continuous term, and departure from linearity by including a quadratic term. Spearman correlations were computed and P values <0.05 were considered to be statistically significant.

Hypothesis-driven interactions with childhood height to predict adult BMI were tested by including an interaction term; e.g., childhood BMI × childhood height. Childhood BMI and height were stratified according to CDC reference quintiles to analyze their interaction in predicting young adult BMI. We performed a global test for interaction by including childhood BMI and height as categorical variables in the model. We then analyzed whether childhood height and adult BMI were linearly associated according to childhood BMI strata, and if these linear trends differed according to BMI strata. Similarly, we analyzed the association of childhood BMI and adult BMI according to childhood height strata. In addition, test for trend in predicting adult BMI was analyzed for childhood height quintiles across the childhood BMI quintile strata and for childhood BMI quintiles across the childhood height strata. The analyses were performed using a linear mixed model to account for the school cluster and all the models were adjusted by gender, age, site, ethnicity, and intervention arm. Analysis was performed in SAS (version 9; SAS Institute, Cary, NC) and graphical displays performed in Splus (version 6; MathSoft, Seattle, WA).

RESULTS

Summary statistics describing the study sample are presented in Table 1. The population was ethnically diverse with 22% self identifying as either "non-Hispanic black" or "Hispanic." Compared to the CDC 2000 reference levels, the cohort was heavier and taller. The median levels for weight, height, and BMI were higher than the mean levels due to the uneven distribution of the sample whereby a higher proportion of children had values in the upper percentiles of weight, height, and BMI in comparison to the middle and lower percentiles. Approximately 25.4% of the children had a BMI that placed them above the childhood categorical level for overweight (i.e., ≥85th percentile of the CDC reference). In young adulthood (mean age 18.3 years), the mean BMI was at 24.5 kg/m^2, and 35.6% of the subjects had a BMI that was above the categorical cutoff of 25 for adult overweight.

The longitudinal association of childhood BMI (adjusted for age, gender, site, and intervention) and young adult BMI is presented as smoothed adjusted means in Figure 1. The association of childhood BMI and young adult BMI was approximately linear with an overall slope of 1.29 kg/m^2 (s.e. 0.02, P < 0.0001). Thus, every childhood BMI unit increase was associated with about 1.3 units of increase in adult BMI. The Spearman correlation between adjusted BMI in childhood and BMI in early adulthood was 0.73. The association departed from linearity (P = 0.0012 for the quadratic term). There was no interaction between gender and childhood BMI in predicting adult BMI (P = 0.58).

Table 1 Descriptive statistics

	Descriptive statistics (n = 2,802)	
	Children	Young adults
Age in years (mean (s.d.))	8.7 (0.45)	18.3 (0.5)
Date of measurement	Fall 1991	Spring 2001
Gender (female %)	51.2	
Ethnicity (n (%))		
Non-Hispanic white	2,070 (74%)	
Non-Hispanic black	335 (12%)	
Hispanic	290 (10%)	
Other	107 (4%)	
Weight (kg) (mean (s.d.))	30.9 (6.9)	74.1 (17.5)
Weight percentile*		
Mean (s.d.)	59.6 (28.1)	64.1 (28.5)
Median (25th, 75th %)	62.3 (37.6, 84.9)	70.7 (42.5, 89.4)
Height (cm) (mean (s.d.))	132.5 (6.1)	170.5 (9.4)
Height percentile*		
Mean (s.d.)	53.8 (27.5)	53.7 (28.6)
Median (25th, 75th %)	55.8 (31.3, 77.1)	54.5 (29.2, 79.0)
BMI (mean (s.d.))	17.5 (2.9)	24.5 (5.3)
BMI percentile*		
Mean (s.d.)	59.9 (28.1)	61.9 (29.4)
Median (25th, 75th %)	63.3 (37.9, 85.3)	67.2 (38.7, 88.5)

*Cohort percentiles are based on Centers for Disease Control and Prevention 2000 reference standards (29).

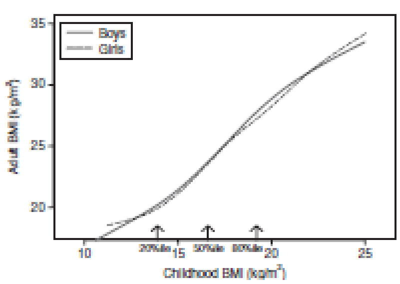

Figure 1 Association of childhood BMI (kg/m²) and adult BMI (kg/m²) by gender, represented by smooth means adjusted for age, ethnicity, site, and intervention. 20th, 50th, and 80th percentiles listed are based on Centers for Disease Control and Prevention age matched height reference units and approximate averages of the genders.

As seen in Figure 2, cross-sectional analysis found that childhood height (adjusted for age, ethnicity, site, and intervention) was associated with childhood BMI. The average linear slope was 0.18 kg/m²/cm (s.e. 0.01, P < 0.0001). Thus, an increase of 5.6 cm in childhood height was associated with an increase of 1 childhood BMI unit. The relationship is curvilinear with a steeper slope at taller heights. A test for nonlinearity was significant with a quadratic term, P < 0.0001. The Spearman correlation between adjusted height and BMI in childhood was 0.33. There was a statistically significant interaction of gender and child height to predict child BMI, whereby there was a stronger association within girls as compared with boys (P = 0.04).

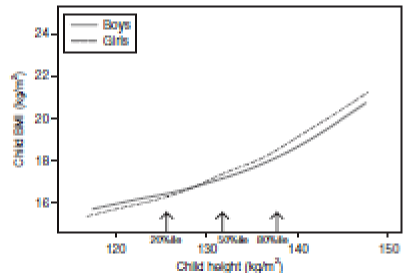

Figure 2 Association of childhood height (cm) and childhood BMI (kg/m²) by gender, represented by smooth means adjusted for age, ethnicity, site, and intervention. 20th, 50th, and 80th percentiles listed are based on Centers for Disease Control and Prevention age matched height reference units and approximate averages of the genders.

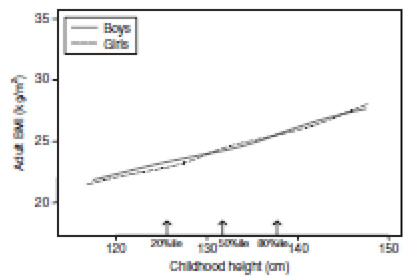

Figure 3 Association of childhood height (cm) and adult BMI (kg/m²) by gender, represented by smooth means adjusted for age, ethnicity, site, and intervention. 20th, 50th, and 80th percentiles listed are based on Centers for Disease Control and Prevention age matched height reference units and approximate averages of the genders.

As seen in Figure 3, longitudinal analysis revealed a statistically significant linear association between childhood height (adjusted for age, ethnicity, site, and intervention) and adult BMI. The linear slope was 0.2 kg/m²/cm, s.e. 0.01, P < 0.0001. Hence, an increase of 4 cm of childhood height was associated with an increase of 1 adult BMI unit. There was no statistical departure from linearity (P = 0.13 for the quadratic term). The Spearman correlation was 0.25. However, after adjustment of childhood height for childhood BMI, there was not a statistically significant association of childhood height and adult BMI (slope = 0.02, s.e. = 0.01, P = 0.12) There was no interaction between gender and childhood height in predicting adult BMI (P value for interaction = 0.10). In adulthood, there was no association between height and BMI (Spearman correlation = 0.03).

Our primary goal was to explore the interaction between childhood height and childhood BMI in predicting young adult BMI. Observed adjusted means of adult BMI stratified by CDC reference quintiles of childhood height and childhood BMI is

Table 2 Predicted adjusted means[a] of adulthood BMI (kg/m^2) according to childhood height and BMI CDC reference quintiles and 95% confidence intervals

		CDC quintiles of child BMI					
		0–20	20–40	40–60	60–80	80–100	
		n = 312	n = 443	n = 548	n = 629	n = 870	P trend
CDC quintiles of child height	0–20	19.6 (18.7, 20.4)	21.2 (20.4, 21.9)	22.3 (21.4, 23.1)	24.7 (23.8, 25.7)	27.5 (26.4, 28.6)	P < 0.0001
	n = 402	n = 81	n = 102	n = 92	n = 75	n = 52	
	20–40	19.8 (18.9, 20.6)	21.5 (20.7, 22.2)	22.7 (22, 23.4)	24.2 (23.5, 24.9)	28.4 (27.7, 29.1)	P < 0.0001
	n = 566	n = 84	n = 108	n = 134	n = 120	n = 120	
	40–60	20.3 (19.3, 21.3)	21.4 (20.6, 22.2)	22.6 (21.9, 23.4)	24.3 (23.6, 24.9)	28.2 (27.6, 28.8)	P < 0.0001
	n = 565	n = 57	n = 97	n = 107	n = 148	n = 156	
	60–80	19.6 (18.6, 20.6)	20.9 (20, 21.7)	22.5 (21.8, 23.1)	24.8 (24.2, 25.5)	28.7 (28.1, 29.2)	P < 0.0001
	n = 662	n = 58	n = 80	n = 137	n = 160	n = 227	
	80–100	20.4 (19, 21.8)	21.5 (20.4, 22.5)	22.2 (21.3, 23.1)	24.3 (23.6, 25)	30.2 (29.7, 30.6)	P < 0.0001
	n = 607	n = 32	n = 56	n = 78	n = 126	n = 315	
	P trend	P = 0.40	P = 0.98	P = 0.83	P = 0.80	P < 0.0001	

CDC, Centers for Disease Control and Prevention.
[a]Adjusted by age, gender, ethnicity, site, and intervention.

presented in Table 2. Overall, we found a statistically significant interaction between childhood height and childhood BMI in predicting adult BMI (P < 0.0001). As seen by the columns in Table 2, within each of the four lower quintiles of childhood BMI, there was no association between childhood height and adult BMI. However, within the top quintile of childhood BMI, there was a significant positive linear association between childhood height quintiles and adult BMI levels (P < 0.0001). Among children in the top quintile of childhood BMI, the tallest children had an adult BMI level of approximately two units more than those children in the middle quintile of childhood height and nearly three BMI units more than those in the lowest quintile of childhood height. After adjusting for childhood BMI, the association between childhood height and adult BMI among the children in the highest BMI quintile became nonsignificant (P = 0.25). In addition, there was no difference between genders (P value for interaction = 0.25).

As seen within the rows of Table 2, within each quintile of childhood height there was a statistically significant linear trend between quintiles of childhood BMI and observed adult BMI (P < 0.0001 for each childhood height quintile). There was a statistically significant difference in the linear trend whereby the highest quintiles of height had steeper slopes. For example, per BMI quintile, the slope for the tallest quintile was 1.02 BMI units higher than the slope of 1.89 BMI units for the shortest quintile of height (P < 0.0001).

DISCUSSION

Our study of 2,802 subjects with measured heights and weights in the 3rd grade (mean age 8.7 years) and then again in the 12th grade (mean age 18.3 years) found a significant interaction between childhood height and childhood BMI for the prediction of young adult BMI. For those children with a BMI that was in the top CDC reference quintile, childhood height had a significant positive association with young adult BMI. Comparing two 3rd grade children of similar age, gender, and ethnicity who have a BMI above the 80th percentile, one whose height is the top 80th to 100th percentile would have a predicted BMI in 12th grade that was approximately two units higher than a child who stood between the 40th to 60th percentile, and nearly three BMI units higher than a child with a height in the lowest quintile. Assuming the child grows to be an average height female (e.g., 5 feet, 4 inches tall), or an average height male (e.g., 5 feet, 10 inches tall), two BMI units signifies ~12 or 14 pounds of weight, respectively. This amount of weight gain has been associated with increased obesity-related cardiovascular risk factors (33,34).

As summarized by Wolff in 1954, studies from the 1930s began documenting that obese children were taller than their peers (35,36). More recently, a cross-sectional analysis of children and adolescents in the Bogalusa Heart Study found a significant association between height and BMI in children aged under 10 years, such that the shorter children (height for age <20th percentile) had only a 1–2% prevalence of obesity (BMI ≥ 95th percentile), whereas those who were taller (height for age >80th percentile) had a prevalence of obesity between 11 and 26% (21). Although numerous previous studies have documented an association of cross-sectional childhood height and BMI (18,21–23), we are aware of few investigations into whether the interaction between childhood height and childhood BMI alters the prediction of adult BMI. Freedman *et al.* analyzed data from 1,055 subjects from the Bogalusa Heart Study in childhood (aged 2–8 years) and then again an average of 18 years later (24). They found that childhood height provided additional information on adult adiposity even if childhood levels of BMI were known. At similar BMI levels, a taller child in their cohort had a higher adult BMI level. However, there discussion section also states that additional analyses found that among children aged ≥9 years, height was not independently related to adult adiposity. The subjects in our study were nearly 9 years of age, and thus our finding that child height adjusted for child BMI was not statistically independently associated with adult BMI is likely consistent with their findings.

Our results confirmed several associations seen in past research. Specifically, we found a significant positive association between childhood BMI and young adult BMI. Childhood BMI was found to account for 53% of the variation in young adult BMI. We also found significant positive associations between childhood height and childhood BMI, and between childhood height and adult BMI. However, after adjustment for childhood BMI, there was no longer an association between childhood height and adult BMI. Thus, childhood height was not an independent predictor of adult BMI. In young adults, we found no association between height and BMI.

In a longitudinal analysis of 626 subjects from the Bogalusa Heart Study, Freedman *et al.* found that the effect of childhood height on adult BMI was "strongest among children who were relatively heavy" (25). Our analysis was consistent with this finding as the association between child height and adult BMI occurred only in children with a BMI in the upper quintile. These results support a model whereby proximal obesogenic factors may be causing an increase in both childhood BMI and childhood skeletal growth and maturation. It is important to note that the association of childhood height and adult BMI among those in the top quintile of childhood BMI exists for far >20% of the current population. In our study, 31% of the subjects had a childhood BMI that was in the upper quintile of the BMI-for-age CDC reference, and the proportion in the current US population is even higher. National Health and Nutrition Examination Survey data for the years 1999–2004 suggest that ~37% of children in the United States, aged 6–11 years, have BMI levels in only the top 15 percentiles (37). Thus, the association between height in 3rd grade and adult BMI for those children with elevated childhood BMI may pertain to nearly half of the current US population of similar aged children. Furthermore, these are the same children that are at most risk for adult overweight and obesity. In our study, of the 870 children who had a BMI over the 80th percentile, 345 (40%) went on to become overweight as young adults (BMI ≥ 25 and <30), and another 305 (35%) went on to become obese (BMI ≥ 30) as young adults. Thus, the association between childhood height and adult BMI occurs in a large proportion of children in today's society, and in those children who need the closest monitoring due to their high risk of becoming overweight and obese.

There are several factors about the CATCH dataset that strengthen our findings. We are unaware of any published study in the United States with a larger number of subjects with measured heights and weights in both childhood and in late adolescence/early adulthood. The subjects were from four geographically and culturally distinct areas of the United States, and ethnically diverse. The childhood measurements were done in the years 1992–1993 and the early adult measurements were completed in the years 2000–2001. Thus, the children grew up in a US environment well after the start of the rise in obesity rates seen in the 1970s and 1980s.

There were also limitations to our study. Only 55% of the original cohort was available for the longitudinal analyses. Analysis of the longitudinal cohort suggests that they were generally similar to the original cohort. The earliest CATCH measurements were carried out in the 3rd grade, with the children being ~8–9 years of age, and the follow-up measurements were collected when the subjects were in 12th grade at an average of 18.3 years of age. Our findings would have likely been stronger if we had measurements from earlier in childhood and later in adulthood. We assumed that the stature of the 12th graders was their adult height, although skeletal maturation was not assessed. A large longitudinal study in Sweden found that 99.2% of their subjects had reached final height by 18 years of age (26).

We believe that our findings raise some important questions for future research. It would be of interest to know whether childhood height interacts with body fat measurements *per se* to predict adult obesity and obesity-related cardiovascular risk factors. Use of body fat measurements would also serve to avoid the statistical conundrum that is inherent when evaluating both height and BMI, the latter including height-squared in the equation. Can the assessment of future obesity risk in a child that is both tall and overweight be improved by body fat measurements, or by evaluation of skeletal maturity?

Our results have potential implications for clinical practice. At present, when a clinician or a parent assesses a child whose BMI is high, but whose stature is also high, there may be the hope that the child will "thin out" and become a tall and normal weight adult. Thus, increased stature may be interpreted to be protective toward the risk of subsequent obesity. However, our findings suggest the opposite. For children in the upper BMI percentiles, those with increased height had higher predicted levels of young adult BMI.

Obesity is associated with excessive morbidity and mortality in the United States and in much of the world (20,38–40). This longitudinal prospective study of 2,802 subjects with measured heights and weights in 3rd grade, and again in 12th grade, found that children with a BMI above the 80th percentile went on to have mean BMI levels in young adulthood that were in the overweight to obese range. Given the strong association between childhood obesity and adult obesity (4–10), it is important to understand factors of childhood growth that predict excessive body weight in adulthood. Our study found a positive association between childhood height and young adult BMI in children with a childhood BMI at or above the 80th percentile of CDC standards. Among children with higher BMI levels, those who were taller, as compared to those who were shorter, had significantly higher young adult BMI levels. This pattern seems primarily due to the positive association of childhood height and childhood BMI. There is a need for further research into the proximal factors causing early increases in both childhood height and childhood BMI. Clinicians should recognize the risk of excess body weight in young adulthood for all children who have a high BMI, and pay special attention to those who are tall, because their childhood height will not protect them from subsequent weight gain and elevated BMI.

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DISCLOSURE
The authors declared no conflict of interest.

REFERENCES
1. York DA, Rössner S, Caterson I *et al.* Prevention Conference VII: obesity, a worldwide epidemic related to heart disease and stroke: Group I: worldwide demographics of obesity. *Circulation* 2004;110:e463–e470.
2. Surgeon General's Call to Action: A call to action to prevent and decrease overweight and obesity. <http://www.surgeongeneral.gov/topics/obesity/> (2007). Accessed 30 August 2007.
3. Healthy People 2010. <http://healthypeople.gov/document/pdf/Volume2/19Nutrition.pdf> (2007). Accessed 30 August 2007.
4. Parsons TJ, Power C, Logan S, Summerbell CD. Childhood predictors of adult obesity: a systematic review. *Int J Obes Relat Metab Disord* 1999;23(Suppl 8):S1–S107.
5. Freedman DS, Khan LK, Serdula MK *et al.* The relation of childhood BMI to adult adiposity: the Bogalusa Heart Study. *Pediatrics* 2005;115:22–27.
6. Guo SS, Huang C, Maynard LM *et al.* Body mass index during childhood, adolescence and young adulthood in relation to adult overweight and adiposity: the Fels Longitudinal Study. *Int J Obes Relat Metab Disord* 2000;24:1628–1635.
7. Whitaker RC, Wright JA, Pepe MS, Seidel KD, Dietz WH. Predicting obesity in young adulthood from childhood and parental obesity. *N Engl J Med* 1997;337:869–873.
8. Clarke WR, Lauer RM. Does childhood obesity track into adulthood? *Crit Rev Food Sci Nutr* 1993;33:423–430.
9. Field AE, Cook NR, Gillman MW. Weight status in childhood as a predictor of becoming overweight or hypertensive in early adulthood. *Obes Res* 2005;13:163–169.
10. Whitlock EP, Williams SB, Gold R, Smith PR, Shipman SA. Screening and interventions for childhood overweight: a summary of evidence for the US Preventive Services Task Force. *Pediatrics* 2005;116:e125–e144.
11. Bellizzi MC, Dietz WH. Workshop on childhood obesity: summary of the discussion. *Am J Clin Nutr* 1999;70:S173–S175.
12. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ* 2000;320:1240–1243.
13. Dietz WH, Robinson TN. Use of the body mass index (BMI) as a measure of overweight in children and adolescents. *J Pediatr* 1998;132:191–193.
14. Barlow SE, Dietz WH. Management of child and adolescent obesity: summary and recommendations based on reports from pediatricians, pediatric nurse practitioners, and registered dietitians. *Pediatrics* 2002;110:236–238.
15. Poskitt EM. Defining childhood obesity: the relative body mass index (BMI). European Childhood Obesity group. *Acta Paediatr* 1995;84:961–963.
16. Lobstein T, Baur L, Uauy R. Obesity in children and young people: a crisis in public health. *Obes Rev* 2004;5(Suppl 1):4–104.
17. Gortmaker SL, Must A, Perrin JM, Sobol AM, Dietz WH. Social and economic consequences of overweight in adolescence and young adulthood. *N Engl J Med* 1993;329:1008–1012.
18. Freedman DS, Khan LK, Dietz WH, Srinivasan SR, Berenson GS. Relationship of childhood obesity to coronary heart disease risk factors in adulthood: the Bogalusa Heart Study. *Pediatrics* 2001;108:712–718.
19. Guo SS, Wu W, Chumlea WC, Roche AF. Predicting overweight and obesity in adulthood from body mass index values in childhood and adolescence. *Am J Clin Nutr* 2002;76:653–658.
20. Overweight, obesity, and health risk. National Task Force on the Prevention and Treatment of Obesity. *Arch Intern Med* 2000;160:898–904.
21. Freedman DS, Khan LK, Serdula MK *et al.* Inter-relationships among childhood BMI, childhood height, and adult obesity: the Bogalusa Heart Study. *Int J Obes Relat Metab Disord* 2004;28:10–16.
22. Williams SM. Weight and height growth rate and the timing of adiposity rebound. *Obes Res* 2005;13:1123–1130.
23. Freedman DS, Thornton JC, Mei Z *et al.* Height and adiposity among children. *Obes Res* 2004;12:846–853.
24. Freedman DS, Khan LK, Mei Z *et al.* Relation of childhood height to obesity among adults: the Bogalusa Heart Study. *Pediatrics* 2002;109:E23.
25. Freedman DS, Kettel KL, Serdula MK, Srinivasan SR, Berenson GS. BMI rebound, childhood height and obesity among adults: the Bogalusa Heart Study. *Int J Obes Relat Metab Disord* 2001;25:543–549.
26. He Q, Karlberg J. BMI in childhood and its association with height gain, timing of puberty, and final height. *Pediatr Res* 2001;49:244–251.
27. Perry CL, Stone EJ, Parcel GS *et al.* School-based cardiovascular health promotion: the child and adolescent trial for cardiovascular health (CATCH). *J Sch Health* 1990;60:406–413.
28. Webber LS, Osganian V, Luepker RV *et al.* Cardiovascular risk factors among third grade children in four regions of the United States. The CATCH Study. Child and Adolescent Trial for Cardiovascular Health. *Am J Epidemiol* 1995;141:428–439.
29. Kuczmarski RJ, Ogden CL, Grummer-Strawn LM *et al.* CDC growth charts: United States. *Adv Data* 2000;1–27.
30. A SAS program for the CDC 2000 growth charts. <http://www.cdc.gov/nccdphp/dnpa/growthcharts/sas.htm> (2007). Accessed 30 August 2007.
31. Barlow SE. Expert Committee. Expert committee recommendations regarding the prevention, assessment, and treatment of child and adolescent overweight and obesity: summary report. *Pediatrics* 2007;120(Suppl 4):S164–S192.
32. Hastie T, Tibshirani R. *Generalized Additive Models.* Chapman and Hall: London, 1990.
33. Gelber RP, Gaziano JM, Manson JE, Buring JE, Sesso HD. A prospective study of body mass index and the risk of developing hypertension in men. *Am J Hypertens* 2007;20:370–377.
34. Wannamethee SG, Shaper AG, Walker M. Overweight and obesity and weight change in middle aged men: impact on cardiovascular disease and diabetes. *J Epidemiol Community Health* 2005;59:134–139.
35. Wolff OH. Obesity in childhood; a study of the birth weight, the height, and the onset of puberty. *Q J Med* 1955;24:109–123.
36. Bruch H. Obesity in childhood: physical growth and development of obese children. *Am J Dis Child* 1939;58:457–484.
37. Ogden CL, Carroll MD, Curtin LR *et al.* Prevalence of overweight and obesity in the United States, 1999–2004. *JAMA* 2006;295:1549–1555.
38. Flegal KM, Graubard BI, Williamson DF, Gail MH. Excess deaths associated with underweight, overweight, and obesity. *JAMA* 2005;293:1861–1867.
39. Asia Pacific Cohort Studies Collaboration. The burden of overweight and obesity in the Asia-Pacific region. *Obes Rev* 2007;8:191–196.
40. Andreyeva T, Michaud PC, van SA. Obesity and health in Europeans aged 50 years and older. *Public Health* 2007;121:497–509.

Appendix B

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NS British Journal of Nutrition

Invited Commentary

Shorter adults, yet taller children: what's up?

We know that obesity tracks steadily from childhood into young adulthood, and then onward into middle age. We know that tall children tend to become tall adults. Yet, the study in this issue of the *British Journal of Nutrition* by Bosy-Westphal *et al.* [1] finds that heavier children are taller than average and heavier adults are shorter than average. What's up with that?

Although obesity is truly excessive body fat in relation to lean mass, the definition of 'excessive' has not been standardised. Given the difficulty of accurately measuring body fatness, the assessment and treatment of obesity are most commonly based on the measure of BMI, defined as weight (kg) divided by the height (m^2). This formula, originally known as the Quetelet index, was described in 1832 by Adolphe Quetelet, a Belgian statistician. Quetelet noted that beyond the first few years of life, the weights of individuals increase proportional to the square of their heights. While critics accurately point out the failure of BMI to correlate with body fatness in certain individuals (for example, in very muscular athletes), it has proved generally accurate as a measure for the study of populations.

A tenet of both the Quetelet index and our sense of fairness is that obesity is independent of height. With the exception of environments where nutrition is inadequate, it is felt that height is genetically determined, and an individual's weight is due to a combination of their height and behaviours determining energy balance (energy-in minus energy-out). Obesity, it is believed, is an equal opportunity condition. However, some past research, confirmed by this large cross-sectional analysis by Bosy-Westphal *et al.* [1], has questioned this assumption.

Using cross-sectional data from a variety of weight-management facilities (183 176 women and 30 628 men) and the Kiel Obesity Prevention Study (6240 girls and 6171 boys), Bosy-Westphal *et al.* [1] assessed the relationship between obesity and height in adults and in children. For the adults, they found a higher prevalence of obesity among those who were shorter. This observation has been noted in a few past studies, with the association strongest when evaluating obesity-related cardiovascular risk factors and the shortness of leg length specifically (rather than total length)[2–6]. However, most studies on obesity have not commented on any association between adult height and adult obesity, perhaps assuming that no relationship exists.

If we are to combat the adult obesity epidemic, it is imperative to decrease the rate of childhood obesity. Childhood BMI has a strong correlation with adult BMI. Although we may have a mental image of the short and overweight child, in fact, studies from the 1930 s began documenting that obese children are taller than their peers[7,8]. More recent investigations, and the childhood cohort studied by Bosy-Westphal *et al.* [1], confirm this association[9–12].

In summary, using very large cohorts, Bosy-Westphal *et al.* [1] have provided us with an analysis documenting the height–obesity relationship of two generations, and left us with a conundrum. Since BMI in childhood is directly correlated with BMI in adulthood, and taller children tend to be taller adults, the positive association of height and obesity in children seems to contradict the inverse association of height and obesity in adults. Why? Some of the answer appears to be that the excess energy intake that promotes obesity in children also speeds up the body maturation process. An overweight 8-year-old child may have the anatomy and physiology of a normal-weight 10-year-old child. This concept should not be used as an excuse for the child's weight by the argument that they are not overweight, but just measured at the wrong age cut-off. In fact, it seems that these tall and overweight children have an even higher risk of becoming overweight young adults compared with their overweight peers who are shorter[12,13]. Using BMI as a continuous variable, for younger children (aged 2–8 years) childhood height may have an independent effect (i.e. even after adjusting for childhood BMI) on adult BMI[13]. Thus, increased height in children may be a surrogate marker for higher risk of obesity in later life. On the surface, this may suggest that these overweight and tall children become overweight and short adults. The authors pose a possible explanation for this whereby the 'preterm skeletal maturity in obese children may limit [subsequent linear] growth and final height in adults'. As support, they cite articles noting that 'the countries with the tallest adults have the lowest rates of obesity'[14,15].

However, beware of conclusions regarding longitudinal associations derived from ecological cross-sectional studies done simultaneously on different generations! The adults in the study by Bosy-Westphal *et al.* [1] had a mean age of approximately 43 years and were assessed between the years of 1996 and 2006. Thus, many grew up before the childhood obesity epidemic. Additionally, the study found an inverse relationship between age and height (with a range from the shortest to the tallest of approximately 15 years). Since individuals tend to gain weight with age, the inverse association of height and BMI in the adults may be a function of the older subjects being heavier. Given the recent gains in adult height (especially in Europe), these older subjects may also have been shorter due to generational, and not individual reasons.

Since the evidence seems overwhelming that obese children are taller than their non-obese peers, what other possibilities might explain the authors' findings that the obese adults were shorter than average? The authors offer one very interesting possibility: food serving sizes. Serving sizes of foods bought at a market or a restaurant are similar for tall and short individuals. Tall individuals have higher BMR of energy expenditure and thus can better tolerate larger intakes. Since many individuals consume food based on visual cues[16], it is reasonable that shorter individuals would take in relatively more energy than their body needs. Put another way, the very large serving sizes offered in many countries may be adversely affecting short individuals more than tall individuals.

Another possible explanation for obesity having different associations with height in the adult and child cohorts may have been due to recruitment issues. The children came from a diverse sample of the population. However, the adults came from weight-loss programmes. Since cultural issues of body morphology may be a driving force for someone to enter a weight-loss programme, heavy individuals who are also short may have been oversampled.

Still, this study and others evaluating the relationship of obesity with stature leave us with some fascinating issues for research.

First and foremost, more longitudinal studies are needed to assess the tracking of both BMI and height from pre-pubescent children into adulthood. This is especially important to follow children who grew up in the recent era of the childhood obesity epidemic.

Until longitudinal studies are available, obesity researchers need to include analyses that are stratified by height, even if the findings are null. If adult obesity is consistently associated with shortness, and if serving sizes are a potential explanation, then perhaps this relationship would be stronger in more recent cohorts as compared with cohorts from the pre-'super-size me' days.

We should seek to find any easily measured markers that could distinguish the child who is tall because he/she is destined to be tall from the one who is tall from excessive energy intake.

Even with these research questions outstanding, some clinical changes can be justified.

Do not use advanced childhood height as an excuse for excessive childhood weight. When evaluating a child who is overweight and also tall, one may hope that the child's weight growth will slow, that his/her height growth pattern will continue, and his/her BMI will normalise. From this perspective, tallness may be interpreted as protective against future obesity. However, it appears that the exact opposite may be true.

Follow childhood growth closely beyond the early immunisation years. The medical profession is very good at following children through their first few years of life. However, we miss the changes in adolescence, which is where the action seems to lie for the issue of skeletal growth patterns. We must pay special attention to the height trajectories of overweight children, many of whom enter puberty taller than their peers.

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References

1. Bosy-Westphal A, Plachta-Danielzik S, Dörhöfer R-P, *et al.* (2008) Short stature and obesity: positive association in adults but inverse association in children and adolescents. *Br J Nutr* (epublication ahead of print version).
2. Hermanussen M, Sunder M, Voigt M, *et al.* (2005) Morbid obesity is associated with short stature. *J Pediatr Endocrinol Metab* **18**, 647–650.
3. Velasquez-Melendez G, Martins IS, Cervato AM, *et al.* (1999) Relationship between stature, overweight and central obesity in the adult population in Sao Paulo, Brazil. *Int J Obes Relat Metab Disord* **23**, 639–644.
4. Gunnell D, Whitley E, Upton MN, *et al.* (2003) Associations of height, leg length, and lung function with cardiovascular risk factors in the Midspan Family Study. *J Epidemiol Community Health* **57**, 141–146.
5. Frisancho AR (2007) Relative leg length as a biological marker to trace the developmental history of individuals and populations: growth delay and increased body fat. *Am J Hum Biol* **19**, 703–710.
6. Lawlor DA, Ebrahim S & Davey SG (2002) The association between components of adult height and type II diabetes and insulin resistance: British Women's Heart and Health Study. *Diabetologia* **45**, 1097–1106.
7. Wolff OH (1955) Obesity in childhood; a study of the birth weight, the height, and the onset of puberty. *Q J Med* **24**, 109–123.
8. Bruch H (1939) Obesity in childhood: physical growth and development of obese children. *Am J Dis Child* **58**, 457–484.
9. Williams SM (2005) Weight and height growth rate and the timing of adiposity rebound. *Obes Res* **13**, 1123–1130.
10. Freedman DS, Khan LK, Dietz WH, *et al.* (2001) Relationship of childhood obesity to coronary heart disease risk factors in adulthood: the Bogalusa Heart Study. *Pediatrics* **108**, 712–718.
11. Freedman DS, Thornton JC, Mei Z, *et al.* (2004) Height and adiposity among children. *Obes Res* **12**, 846–853.
12. Stovitz SD, Pereira MA, Vazquez G, *et al.* (2008) The interaction of childhood height and childhood BMI in the prediction of young adult BMI. *Obesity (Silver Spring)* **16**, 2336–2341.
13. Freedman DS, Khan LK, Mei Z, *et al.* (2002) Relation of childhood height to obesity among adults: the Bogalusa Heart Study. *Pediatrics* **109**, E23.
14. Hauspie RC, Vercauteren M & Susanne C (1997) Secular changes in growth and maturation: an update. *Acta Paediatr Suppl* **423**, 20–27.
15. Garcia J & Quintana-Domeque C (2007) The evolution of adult height in Europe: a brief note. *Econ Hum Biol* **5**, 340–349.
16. Wansink B, Painter JE & North J (2005) Bottomless bowls: why visual cues of portion size may influence intake. *Obes Res* **13**, 93–100.

Appendix C

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2: Stovitz SD, Pereira MA, Vazquez G, Lytle LA, Himes JH. The interaction of childhood height and childhood BMI in the prediction of young adult BMI. Obesity (Silver Spring). 2008 Oct;16(10):2336-41. Epub 2008 Jul 24. PubMed PMID: 18719630; PubMed Central PMCID: PMC2747360.

3: Stovitz SD. Shorter adults, yet taller children: what's up? Br J Nutr. 2009 Aug;102(3):329-30. Epub 2009 Jan 28. PubMed PMID: 19175948.

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