Published in final edited form as:

Am J Hum Biol. 2010 ; 22(6): 830–835. doi:10.1002/ajhb.21091.

RELATIONSHIPS BETWEEN SERIAL CHILDHOOD ADIPOSITY MEASURES AND ADULT BLOOD PRESSURE: THE FELS LONGITUDINAL STUDY

Roy T. Sabo, PhD¹, Zheng Lu, PhD¹, Stephen Daniels, MD², and Shumei S. Sun, PhD¹

¹Department of Biostatistics, School of Medicine, Virginia Commonwealth University, Richmond, Virginia, USA

²Department of Pediatrics, School of Medicine, University of Colorado

Abstract

Objectives—Several studies have shown that causes of adult hypertension arise in childhood, and obesity may be a potential cause or at least a mitigating factor in this development. Body mass index is a well studied obesity metric, yet other potential adiposity measures such as percent body fat and waist circumference have been somewhat less considered. The purpose of this study is to determine associations between these alternative serial childhood adiposity measures and adulthood blood pressure.

Methods—Measurements from participants in the Fels Longitudinal Study were used to summarize childhood adiposity, represented by childhood measurements of percent body fat and height-adjusted waist circumference. These subjects also provided systolic and diastolic blood pressure as adults. Childhood adiposity levels were categorized as high or low as compared to the respective upper quartile, and associations with adult blood pressure were measured using Poisson regression to estimate the number of expected occurrences of elevated adiposity during childhood. Adult lifestyle covariates and adiposity were accounted for using multiple linear regression.

Results—Summary indices of the childhood adiposity measures were significantly associated with both adult blood pressure metrics in men and women, though some of these associations were altered or reduced in the presence of adult lifestyle characteristics and adult adiposity measures.

Conclusions—Childhood measures of percent body fat and height-adjusted waist circumference have an effect on adult blood pressure, though the effect can be mitigated by adult lifestyles.

Keywords

blood pressure; percent body fat; waist circumference; Fels Longitudinal Study

INTRODUCTION

Hypertension affects nearly 50 million Americans and nearly 1 billion people worldwide, and occurs in over two-thirds of individuals after age 65 (Chobanian and others 2003). High blood pressure has been associated with increased risk of cardiovascular disease (CVD), heart attack, heart failure, ischemic heart disease, cardiac abnormalities, stroke and kidney disease, dementia and cognitive impairment (Blake and others 2003; Chobanian and others

Name and complete address for correspondence: Roy Travis Sabo, Assistant Professor of Biostatistics, Theater Row, Room 3032, 730 East Broad Street, P.O. Box 980032, Richmond, VA 23298-0032, Fax: (804) 828-8900, Telephone: (804) 828-3047, rsabo@vcu.edu.

Disclosures: None.

2003; Stamler and others 1993; Whelton and others 1993). Primary hypertension has also been shown to begin in childhood (Berenson and others 1994; Tracy and others 1995). Obesity is an increasingly prevalent risk factor in the development of many diseases and adverse health conditions (Lauer and others 1988; Must and others 1992; Must and Strauss 1999), including CVD (Chobanian and others 2003; Gunnell and others 1988; Hoffmans and others 1988) and hypertension (Chobanian and others 2003), both in children (Figueroa-Colon and others 1997; Freedman and others 1999) and adults (Guo and others 1998; Kiu and others 1996; Lauer and Clarke 1989; Lauer and others 1993; Law and others 2002; Reilly and others 2003; Srinivasan and others 1996). However, the roots of adult hypertension in childhood remain unclear.

Increased adiposity levels have been associated with whole blood viscosity (deSimone and others 1990), and correlation between blood viscosity and hypertension has been established (Devereux and others 2000). Percent body fat, the biological complement of fat free mass, is one adiposity measure that is a correlate of blood pressure in children (Daniels and others 1996; Daniels and others 1995). Waist circumference is another adiposity measure that, if properly adjusted by subject height or some power of subject height (Daniels and others 1988), can add predictive ability of childhood body weight on adult blood pressure (Gillum 1987; Lauer and others 1991). Similarly, hypertensive children who continue to have high blood pressure into adulthood have larger body weight, body mass index (BMI), skinfold thickness, and greater hip and waist circumferences (Lauer and others 1984).

Recent estimates suggest that over 122 million adults are overweight or obese (Flegal and others 2002), and as the prevalence of childhood obesity increases, its relationship with adult cardiovascular morbidity is likely to grow in magnitude (Reilly and others 2003). As obesity and blood pressure track from childhood into adulthood (Beckett and others 1992; Guo and others 1998; Sun and others 2007), and since childhood body size and change in adiposity have been associated with adult blood pressure (Berenson and others 1995; Freedman and others 2001; Lauer and others 1993), it is of interest to determine the relationships between adulthood blood pressure and alternative measures of obesity in childhood, such as percent body fat and waist circumference. The primary analysis of this study is to measure the association between the proportions of high serial childhood adiposity measurements and adult levels of systolic and diastolic blood pressure. These relationships are further studied in secondary analyses which account for adult adiposity measurements and other adult lifestyle characteristics, including age, alcohol use and smoking status, use of blood pressure medication and level of physical activity are also examined.

METHODS

Study Sample

This study examined Caucasian male and female participants of the Fels Longitudinal Study (FLS) who were at least 20 years of age by the end of data collection on 6/27/2008. All subjects in this study provided systolic and diastolic blood pressure, and also had long-term serial childhood adiposity data from early childhood. FLS participants are generally enrolled at birth and are not selected in regard to factors known to be associated with disease, body composition or other clinical conditions. Children were examined semi-annually (near their birthdays and 6 months following) until 18 years of age, then biannually to 24 years of age. Subsequent adult measurements occurred at five-year intervals until age 40; thereafter, the measures were taken at two-year intervals. All participants signed an informed consent statement, and procedures were approved by the Institutional Review Boards at Wright State University and Virginia Commonwealth University.

Measurements

Systolic (SBP, mmHg) and diastolic blood pressure (DBP, mmHg) were measured in adult FLS participants in a standardized manner using a mercury sphygmomanometer as recommended by the Second NHLBI Task Force on blood pressure (BP) Control. Three BP readings are taken from subjects seated in upright positions by rapidly inflating the arm cuff to the maximum level and deflating at a rate of 2 mmHg per second, with 30 seconds rest between each determination. The first appearance of two consecutive beats determines the first Korotkoff phase (K1); K4 is the point where the sound becomes muffled; and K5 is when the sound disappears. Diastolic BP is recorded at K5. Both measures are recorded as the average of the three readings.

Serial childhood measurements of percent body fat (PBF, %) and waist circumference (WC, cm) were obtained from ages ~5.5 to 18 years. PBF was measured in two ways. In the first

method PBF is calculated as $\frac{d_1 d_2 - d_2}{BD(d_1 - d_2)} \times 100$ (Guo and others 1997), where body density (BD) was determined from underwater weighing and residual volume as measured on a Gould 2100 computerized spirometer (Guo and others 1989), d_1 is the density of fat-free mass and d_2 is the density of fat. In the second method, PBF is obtained from underwater weighing and dual energy x-ray absorptiometry (DXA) using a Hologic QDR 4500. The DXA PBF measurements (PBF_{DXA}) were converted to the underwater PBF scale using the expression $-2.0337 + 1.1285 \times PBF_{DXA}$. WC was measured twice at the suprailiac crest, with the average value used for statistical analysis. WC is then adjusted by dividing by height-squared to reduce the effect of various body sizes. These adiposity measures (both PBF and WC/ht²) for each subject are compared to the corresponding 75th percentiles for all FLS participants at those ages, and adiposity status is then categorized into high (75th percentile or above) or normal (below 75th percentile). The percentiles used in these transformations are presented by gender in Figure 1 for PBF and Figure 2 for height-adjusted WC. After this transformation, each subject has a series of categorical PBF and WC measures which are summarized to represent the proportion of total high childhood adiposity measurements. Adult PBF and WC measurements were also obtained for use in the secondary analysis, where the adult WC measures are also adjusted by the square of height, with the resulting ratio multiplied by 1,000 for ease of interpretation.

Covariates

Lifestyle characteristics may also mitigate the relationship between body composition and hypertension. Increased levels of physical activity have been shown to affect body composition by increasing the ratio of fat free mass to body fat (Guo and others 1999; Ross and Janssen 2001) and can lower blood pressure (Braith and others 1994). Smoking has also been associated with increased left ventricular mass, which can increase the percentage of both internal aortic surface involved with fibrous plaques and fatty streaks in coronary vessels (Heckbert and others 2006). Adult lifestyle characteristics were ascertained through self-administered questionnaires, the responses to which were used to classify subjects as current smokers (yes or no) or moderate/high alcohol users (yes or no). Physical activity (PA) was measured using specific questions from the Baecke questionnaire of Habitual Physical Activity measuring how physically active the person feels he/she was compared to his/her peers (Baecke and others 1982). Men and women were classified as having low PA if they responded that they were physically less active than their peers, and were otherwise classified as having normal/high PA if they responded that they were physically equal or more active than their peers. Comprehensive lists of current medications were examined to classify subjects based on blood pressure medication (BPMed) use. Subject age at the time of adulthood blood pressure and adiposity measurement was also recorded.

Statistical Analyses

Continuous data are summarized with means and standard deviations, while categorical data are summarized with frequencies and percentages. Gender differences are determined using *t*-tests for continuous data and Fisher's exact test for categorical data. The primary analysis of the relationship between adult blood pressure and the number of childhood measurements of high adiposity is examined using Poisson regression, with the total number of childhood measurements included as an offset. The secondary analysis is conducted by estimating multiple linear regressions to measure the association between adult blood pressure and the proportions of high childhood adiposity measures, while adjusting for adult lifestyle characteristics and adult adiposity, as well as any interactions between covariates and the childhood adiposity measures. All subjects are included in the primary analysis, while only those subjects who provided six or more childhood measurements are included in the secondary analysis. This exclusion is needed to ensure fidelity of the estimated childhood proportions. For all regressions in the secondary analysis, a covariate is removed from model consideration if the corresponding *p*-value is greater than 0.20, provided there is not an interaction term involving that covariate remaining in the model. The analyses for percent body fat and waist circumference are conducted separately, as are the analyses for male and female subjects. Since the set of covariates are common to both SBP and DBP for each subject, the two blood pressure measures are also analyzed separately.

RESULTS

The data are summarized in Table 1, which provides sample sizes and average values for SBP, DBP, adult adiposity and age, and frequencies and proportions for the categorical PBF and WC measures as well as the categorical covariates for alcohol consumption, smoking status, use of blood pressure medication and level physical activity. For categorical data, summaries are provided both for the entire sample and for the reduced sample consisting of only those subjects with six or more childhood adiposity measures. For PBF this decision rule results in a substantial reduction (Men: 122 in the full sample and 64 in the reduced sample; Women: 133 in the full sample and 57 in the reduced sample), while for WC most subjects were retained (both four men and four women were removed). The summaries are divided by gender and tabulated separately for PBF and WC, as not all subjects provided both measures. The childhood adiposity distributions are similar for men and women for both measures, with most subjects having low PBF and WC throughout childhood. In the WC sample there is a slight increase in prevalence at the highest level, representing subjects with mostly high WC measures throughout childhood. All subjects considered were less than 50 years of age. In general, women had lower SBP, DBP and adult adiposity measures than men, and consumed alcohol and smoked with lower prevalence. Proportions of subjects reporting use of blood pressure medications were similar across genders, as were the proportions reporting low levels of physical activity.

Percent Body Fat

Utilizing the full study sample and without adjusting for any covariates in the primary analysis using Poisson regression, there are significant positive associations (Table 2a) between adult blood pressure and childhood percent body fat for both blood pressure measures in men (*p*-values < 0.001) and women (SBP: *p*-value = 0.001; DBP: *p*-value = 0.005). After removing subjects with fewer than six childhood adiposity measurements, there are 64 men and 57 women remaining for the secondary PBF analysis using multiple linear regression. For male subjects (Table 3a), the significant positive relationships between childhood PBF and adult blood pressure are maintained (*p*-values < 0.05) after adjusting for adult lifestyle covariates. While none of the covariates were significant for SBP, for DBP there was a significant positive effect with age (*p*-value = 0.035) and a significant negative

effect with blood pressure medication (p -value = 0.044). For female subjects (Table 3a), the significant positive association between childhood PBF and adult blood pressure was maintained for SBP (p -value = 0.027) but not for DBP (p -value = 0.19). None of the covariates were significant in the analysis for females. In both men and women, adjusting for adult PBF accounted for most of the relationship between childhood PBF and adult blood pressure (Table 3b), and was itself significantly and positively associated with SBP (p -value = 0.027) and DBP (p -value = 0.002) in men and with SBP (p -value = 0.009) but not DBP in women. In men the use of blood pressure medication (p -value = 0.016) and the level of physical activity (p -value = 0.048) were significantly and negatively associated with adult DBP, while in women age was significantly and negatively associated with DBP (p -value = 0.013). No covariates were significantly associated with adult SBP in men or women.

Waist Circumference

Utilizing the full study sample and without adjusting for any covariates in the primary analysis using Poisson regression, childhood waist circumference (adjusted for height) is significantly associated with adult blood pressure (Table 2b) in men and women (p -values < 0.001). The relationships are positive for men and, interestingly, negative for women. After removing subjects with fewer than six childhood adiposity measurements, there are 99 men and 103 women remaining for the secondary analysis WC analysis using multiple linear regression. For male subjects (Table 4a), there is weak evidence of a positive relationship between childhood WC and adult SBP (p -value = 0.058) and weaker evidence of a relationship with adult DBP (p -value = 0.097) after adjusting for covariates. Alcohol use had a significant and positive effect on SBP (p -value = 0.048), while age had a significant and positive effect on DBP (p -value = 0.018). For female subjects (Table 4a), there was no significant relationship between childhood WC and either adult SBP (p -value = 0.22) or DBP (p -value = 0.35), after adjusting for adult lifestyle covariates. There was a significant positive association between age and SBP (p -value 0.042). After further adjusting for adult WC (scaled for height), there was no evidence that childhood WC was associated with adult blood pressure (Table 4b). Adult WC was significantly and positively associated with adult DBP in men (p -value = 0.002) and with adult blood pressure in women (p -values < 0.001). Alcohol was significantly and negatively associated with SBP (p -value = 0.032) and DBP (p -value = 0.023) in men, while age was significantly and positively associated with SBP in men (p -value = 0.010) and women (p -value < 0.001).

DISCUSSION

Our findings suggest that high childhood adiposity (as measured by percent body fat and height-adjusted waist circumference) might be a factor leading to high levels of adult blood pressure, though these associations are altered or reduced when adult adiposity is accounted for. There was evidence that childhood percent body fat is positively associated with adult blood pressure in men and women. While there is evidence that childhood height-adjusted waist circumference is positively associated with adult blood pressure in men, there was also evidence of a negative association in women. In general, the relationships for PBF were maintained more for men than women in the presence of covariates, while the associations were completely confounded when adjusted by adult PBF. Adjusting for covariates reduced the association between WC and adult blood pressure in men and completely reduced it in women. In general, the results also seem to indicate that the relationship between childhood adiposity and adult blood pressure is stronger for SBP than DBP, which has been seen elsewhere (Cook and others 1997; Law and others 2002).

These results are similar to those found in other longitudinal studies, notably the Bogalusa heart study (Freedman and others 2001) and the Muscatine study (Lauer and others 1991; Lauer and Clarke 1989; Lauer and others 1993), where researchers found associations

between childhood BMI and adulthood blood pressure. Like our study, the Bogalusa heart study researchers found the weak relationship between childhood BMI with adult blood pressure was mostly attributable to the strong persistence of weight status between childhood and adulthood. However, both studies focused on adult ages that were considerably younger (Bogalusa: 18–37; Muscatine: 20–30) than in the FLS study (20–50).

The subjects in this study were predominantly white, and the results in this manuscript are not intended to apply to other racial or ethnic groups. It has been shown elsewhere that the prevalence, severity and impact of hypertension are increased in African Americans (Chobanian and others 2003; Kiu and others 1996), though these difference have been shown to disappear when birth weight is accounted for (Cruickshank and others 2005; Kiu and others 1996). Regardless, the results from this study may not be generalizable to non-white populations.

As seen in Table 1, there are high proportions of subjects with no elevated adiposity measurements in childhood for both boys (PBF: 62.4%; WC: 58.3%) and girls (PBF: 61.7%; WC: 57.0%). A similar pattern was observed for BMI among the same subjects as no boys under the age of 12 and girls under the age of 10.5 reported BMI greater than 25 kg/m². During adolescence and early teenage years, between 1% and 9% of boys and girls reported high BMI, and those percentages increased to between 8% and 17% for latter teenage years. These rates may be lower than expected, as childhood obesity in general is increasing in prevalence (Figuerola-Colon and others 1997; Freedman and others 1999; Reilly and others 2003). This may be a construct of the demographic homogeneity in the FLS sample.

The negative relationship between childhood WC and adult blood pressure in women is surprising, as they seemingly imply that women who had larger waist circumferences as children have lower adult blood pressure than do women who had smaller waist circumferences as children. As there is no biological explanation for this to occur, we feel that the finding is spurious and results from possibly unconsidered factors. This relationship will be analyzed further in a subsequent study.

Overweight children vary markedly in terms of body fatness (Freedman and others 2009). Further, even though obesity often persists from childhood into adulthood, obesity criteria vary (Must and Strauss 1999). Levels of waist/height ratio were found to be more strongly associated with adverse risk-factors than were levels of body mass index for age or skinfold thickness (Freedman and others 2009), which is why skinfold measures included in the FLS data source were not included in this analysis. It has also been noted that while hypertension is more prevalent in obese rather than lean subjects, conversely, increased body mass is more common among hypertensive patients (Julius and others 2000). This duality implies that interpretations should focus on associations rather than causations for contemporary measurements, though this need not be the case for sequential measures.

As childhood adiposity is related to adulthood adiposity (Beckett and others 1992; Guo and others 1998; Sun and others 2007), and adult adiposity is related to adult blood pressure (Chobanian and others 2003), it stands to reason that childhood adiposity also plays an albeit non-direct role. While the associations found in this study between childhood adiposity (measured by PBF and WC) and adult blood pressure were weakened in the presence of adult adiposity, this does not mean that only adult adiposity (and not childhood adiposity) is related to adult blood pressure. A closer inspection of pattern of serial childhood adiposity may shed light on the interconnections between these three measures. The pattern of childhood adiposity could take a number of possible forms, including routinely high adiposity measures, intermittently or sporadically high measures, or few to none. By providing a more established connection between these childhood patterns and adult

adiposity, more descriptive ability on adult blood pressure may be achieved. Links to morbidities associated with hypertension may also improve the focus of future research. A study relating childhood body mass index with adult blood pressure will appear elsewhere.

Acknowledgments

We thank two reviewers and the editor, each of whom provided helpful comments and suggestions that undoubtedly improved the presentation of this manuscript. This work was supported by National Heart Lung and Blood Institute (National Institutes of Health) grant R01HL072838-05, as well as by grants U01HL101064, R01HD060913, R01HD038356, DK 071485, HL 072838 and HD 12252.

Supported by: National Heart Lung and Blood Institute (National Institutes of Health) grant R01HL072838-05.

REFERENCES

- Baecke J, Burema J, Frijters J. A short questionnaire for the measurement of habitual physical activity in epidemiological studies. *Am J Clin Nutr.* 1982; 36(5):936–942. [PubMed: 7137077]
- Beckett L, Rosner B, Roche A, Guo S. Serial changes in blood pressure from adolescence into adulthood. *Am J Epidemiol.* 1992; 135(10):1166–1177. [PubMed: 1632426]
- Berenson G, Wattigney W, Bao W, Nicklas T, Jiang X, Rush J. Epidemiology of early primary hypertension and implications for prevention: the Bogalusa Heart Study. *J of Hum Hyper.* 1994; 8:303–311.
- Berenson G, Wattigney W, Bao W, Srinivasan S, Radhakrishnamurthy B. Rationale to study the early natural history of heart disease: The Bogalusa Heart Study. *Am J Med Sci.* 1995; 310:S22–S28. [PubMed: 7503119]
- Blake G, Fifi N, Buring J, Ridker P. Blood Pressure, C-Reactive Protein, and risk of future cardiovascular events. *Circulation.* 2003; 108:2993–2999. [PubMed: 14638538]
- Braith R, Pollock M, Lowenthal D, Graves J, Limacher M. Moderate- and high-intensity exercise lowers blood pressure in normotensive subjects 60 to 79 years of age. *Am J Cardiol.* 1994; 73(15): 1124–1128. [PubMed: 8198040]
- Chobanian AB, Bakris GB, Black HC, Cushman WG, Green L, Izzo J, Jones DM, Materson BO, Paril SW, Wright J, and others. Seventh report on the joint national committee on prevention, detection, evaluation, and treatment of high blood pressure. *Hypertension* 2003; 42:1206–1252 [PubMed: 14656957]
- Cook N, Gillman M, Rosner B, Taylor J, Hennekens C. Prediction of young adult blood pressure from childhood blood pressure, height and weight. *J Clin Epidemiol.* 1997; 50(5):571–579. [PubMed: 9180649]
- Cruickshank J, Mzayek F, Liu L, Kieltyka L, Sherwin R, Webber L, Srinavasan S, Berenson G. Origins of the “Black/White” difference in blood pressure. *Circulation.* 2005; 111:1932–1937. [PubMed: 15837946]
- Daniels S, Kimbal T, Khoury P, Witt S, Morrison J. Correlates of the hemodynamic determinants of blood pressure. *Hypertension.* 1996; 28(1):37–41. [PubMed: 8675261]
- Daniels S, Kimball T, Morrison J, Khoury P, Witt S, Meyer R. Effect of lean body mass, fat mass, blood pressure, and sexual maturation on left ventricular mass in children and adolescents. Statistical, biological, and clinical significance. *Circulation.* 1995; 92(11):3249–3254. [PubMed: 7586311]
- Daniels S, Meyer R, Liang Y, Bove K. Echocardiographically determined left ventricular mass index in normal children, adolescents and young adults. *J Am Coll Cardiol.* 1988; 12(3):703–708. [PubMed: 3403828]
- deSimone G, Devereux R, Chien S, Alderman M, Atlas S, Laragh J. Relation of blood viscosity to demographic and physiologic variables and to cardiovascular risk factors in apparently normal adults. *Circulation.* 1990; 81(1):107–117. [PubMed: 2297818]
- Devereux R, Case D, Alderman M, Pickering T, Chien S, Laragh J. Possible role of increased blood viscosity in the hemodynamics of systemic hypertension. *Am J Cardiol.* 2000; 85:1265–1268. [PubMed: 10802017]

- Figuerola-Colon R, Franklin F, Lee J, Aldridge R, Alexander L. Prevalence of obesity with increased blood pressure in elementary school-aged children. *South Med J*. 1997; 90:806–813. [PubMed: 9258307]
- Flegal K, Carroll M, Ogden C, Johnson C. Prevalence and trends in obesity among US adults. *Journal of the American Medical Association*. 2002; 288:1723–1727. [PubMed: 12365955]
- Freedman D, Dietz W, Srinivasan S, et al. The relation of overweight to cardiovascular risk factors among children and adolescents: the Bogalusa Heart Study. *Pediatrics*. 1999; 103:1175–1182. [PubMed: 10353925]
- Freedman D, Dietz W, Srinivasan S, Berenson G. Risk factors and adult body mass index among overweight children: the Bogalusa heart study. *Pediatrics*. 2009; 123:750–757. [PubMed: 19254998]
- Freedman D, Khan L, Dietz W, Srinivasan S, Berenson G. Relationship of childhood obesity to coronary heart disease risk factors in adulthood: the Bogalusa Heart Study. *Pediatrics*. 2001; 108:712–718. [PubMed: 11533341]
- Gillum R. The association of body fat distribution with hypertension, hypertensive heart disease, coronary heart disease, diabetes and cardiovascular risk factors in men and women aged 18–79 years. *J Chron Dis*. 1987; 40:421–428. [PubMed: 3494034]
- Gunnell D, Frankel S, Nanchahal K, Smith G. Childhood obesity and adult cardiovascular mortality: a 47 year followup study based on the Boyd Orr cohort. *American Journal of Clinical Nutrition*. 1988; 67:1111–1118. [PubMed: 9625081]
- Guo S, Chi E, Wisemandle W, Chumlea W, Roche A, Siervogel R. Serial changes in blood pressure from childhood into young adulthood for females in relation to body mass index and maturational age. *American Journal of Human Biology*. 1998; 10:589–598.
- Guo S, Chumlea W, Roche A, Siervogel R. Age- and maturity-related changes in body composition during adolescence into adulthood: The Fels Longitudinal Study. *International Journal of Obesity*. 1997; 21(12):1167–1175. [PubMed: 9426385]
- Guo S, Roche A, Houtkooper L. Fat-free mass in children and young adults predicted from bioelectric impedance and anthropometric variables. *Am J Clin Nutr*. 1989; 50:435–443. [PubMed: 2773822]
- Guo S, Zeller C, Chumlea W, Siervogel R. Aging, body composition, and lifestyle: the Fels Longitudinal study. *American Journal of Clinical Nutrition*. 1999; 70(3):405–411. [PubMed: 10479203]
- Heckbert S, Post W, Pearson G, Arnett D, Gomes A, Jerosch-Herold M, Hundley W, Lima J, Bluemke D. Traditional cardiovascular risk factors in relation to left ventricular mass, volume, and systolic function by cardiac magnetic resonance imaging: the Multiethnic Study of Atherosclerosis. *J Am Coll Cardiol*. 2006; 48(11):2285–2292. [PubMed: 17161261]
- Hoffmans M, Kromhout D, Coulander CdL. The impact of body mass index of 78 612 Dutch men on 32-year mortality. *Journal of Clinical Epidemiology*. 1988; 41:749–756. [PubMed: 3418364]
- Julius S, Valentini M, Palatini P. Overweight and hypertension: a 2-way street? *Hypertension*. 2000; 35:807–813. [PubMed: 10720599]
- Kiu K, Ruth K, Flack J, Jones-Webb R, Burke G, Savage P, Hulley S. Blood pressure in young blacks and whites: relevance of obesity and lifestyle factors in determining differences. *Circulation*. 1996; 93:60–66. [PubMed: 8616942]
- Lauer R, Anderson A, Beaglehole R, Burns T. Factors related to tracking of blood pressure in children. *Hypertension*. 1984; 6:307–314. [PubMed: 6735452]
- Lauer R, Burns T, Clarke W, Mahoney. Childhood predictors of future blood pressure. *Hypertension*. 1991; 18(3 Suppl):174–181.
- Lauer R, Clarke W. Childhood risk factors for high adult blood pressure: the Muscatine Study. *Pediatrics*. 1989; 84(4):633–641. [PubMed: 2780125]
- Lauer R, Clarke W, Mahoney L, Witt J. Childhood predictors for high adult blood pressure: The Muscatine Study. *Pediatr Clin North Am*. 1993; 40(1):23–40. [PubMed: 8417407]
- Lauer R, Lee J, Clarke W. Factors affecting the relationship between childhood and adult cholesterol levels: the Mustatine Study. *Pediatrics*. 1988; 82:309–318. [PubMed: 3405659]

- Law C, Shiell A, Newsome C, Syddall H, Shinebourne E, Fayers P, Martyn C, Swiet Md. Fetal, infant and childhood growth and adult blood pressure. *Circulation*. 2002; 105:1088–1092. [PubMed: 11877360]
- Must A, Jacques P, Dallal G, Bajema C, Dietz W. Long-term morbidity and mortality of overweight adolescents: A follow-up of the Harvard Growth Study 1922 to 1935. *New England Journal of Medicine*. 1992; 327:1350–1355. [PubMed: 1406836]
- Must A, Strauss R. Risks and consequences of childhood and adolescent obesity. *International Journal of Obesity*. 1999; 23 Suppl 2:S2–S11. [PubMed: 10340798]
- Reilly J, Methven E, McDowell Z, et al. Health consequences of obesity. *Archives of Disease in Childhood*. 2003; 88:748–752. [PubMed: 12937090]
- Ross R, Janssen I. Physical activity, total and regional obesity: dose-response considerations. *Med Sci Sports Exerc*. 2001; 33(6 Suppl):S521–S527. [PubMed: 11427779]
- Srinivasan S, Bao W, Wattigney W, Berenson G. Adolescent overweight is associated with adult overweight and related multiple cardiovascular risk factors. The Bogalusa Heart Study. *Metabolism*. 1996; 45:235–240. [PubMed: 8596496]
- Stamler J, Stamler R, Neaton J. Blood pressure, systolic and diastolic, and cardiovascular risks. *Archives of Internal Medicine*. 1993; 153:598–615. [PubMed: 8439223]
- Sun S, Grave G, Siervogel R, Pickoff A, Arslanian S, Daniels S. Systolic blood pressure in childhood predicts hypertension and metabolic syndrome later in life. *Pediatrics*. 2007; 119(2):237–246. [PubMed: 17272612]
- Tracy R, Newman W, Wattigney W, Berenson GS. Risk factors and atherosclerosis in youth autopsy findings of the Bogalusa Heart Study. *Am J Med Sci*. 1995; 310:S37–S41. [PubMed: 7503122]
- Whelton P, Adams-Campbell L, Appel L, Cutler J, Donato K, Elmer P, Grimm R, Haskell W, Havas S, Horan M, and others. National high blood pressure education program working group report on primary prevention of hypertension. *Archives of Internal Medicine* 1993; 153:1862–1882. [PubMed: 8422207]

Figure 1.
Plot of overall 75th percent body fat (PBF) percentile at each age (years) in Fels Longitudinal Study subjects.

Figure 2. Plot of overall 75th waist circumference (WC, adjusted by height-squared) percentile at each age (years) in Fels Longitudinal Study subjects.

Data summary

Sample size, mean and standard deviation provided for adult systolic (SBP) and diastolic (DBP) blood pressure, adiposity (percent body fat (PBF) and waist circumference (WC)) and age (in years). Frequencies and percentages (%) of subjects provided for percentage of childhood adiposity (AP) measures (PBF or WC) greater than the respective 75th percentile and for adult lifestyle characteristics, including alcohol consumption (Alcohol: yes or no), smoking status (Smoke: yes or no), use of blood pressure medication (BPMed: yes or no) and level of physical activity (PA: low or not low). Categorical variables are summarized for the full study samples (F: first sub-columns) as well as the reduced study samples (R: second sub-columns) where subjects are excluded if they provide fewer than 6 AP measurements during childhood.

Table 1

	PBF				WC			
	Men		Women		Men		Women	
	N	Mean ± SD	N	Mean ± SD	N	Mean ± SD	N	Mean ± SD
SBP*	122	118.0 ± 12.21	133	107.2 ± 11.16	103	118.7 ± 12.16	107	107.5 ± 11.53
DBP*	122	76.8 ± 10.81	133	70.1 ± 9.09	103	77.0 ± 10.97	107	71.0 ± 9.66
Adiposity [†]	106	21.3 ± 8.23	123	34.4 ± 7.60	103	95.5 ± 15.63	107	90.7 ± 14.89
Age	122	33.0 ± 7.82	133	33.6 ± 7.94	103	31.8 ± 6.82	107	32.1 ± 7.01
AP% = 0	F# (%)	R# (%)	F# (%)	R# (%)	F# (%)	R# (%)	F# (%)	R# (%)
0 < AP% ≤ 20	76 (62.3)	34 (53.1)	82 (61.7)	25 (43.9)	60 (58.3)	57 (57.6)	61 (57.0)	60 (58.3)
20 < AP% ≤ 40	13 (10.7)	10 (15.6)	15 (11.3)	11 (19.3)	13 (12.6)	12 (12.1)	15 (14.0)	14 (13.6)
40 < AP% ≤ 60	8 (6.6)	5 (7.8)	16 (12.0)	10 (17.5)	6 (5.8)	6 (6.1)	6 (5.6)	6 (5.8)
60 < AP% ≤ 80	6 (4.9)	3 (4.7)	6 (4.5)	4 (7.0)	6 (5.8)	6 (6.1)	6 (5.6)	6 (5.8)
AP% > 80%	7 (5.7)	6 (9.4)	6 (4.5)	4 (7.0)	7 (6.8)	7 (7.1)	7 (6.5)	7 (6.8)
< 6 Measures	12 (9.8)	6 (9.4)	8 (6.0)	3 (5.3)	11 (10.7)	11 (11.1)	12 (11.2)	10 (9.7)
Alcohol (Yes) [†]	58 (47.0)	--	76 (57.1)	---	4 (3.4)	--	4 (3.3)	---
Smoke (Yes) [§]	86 (70.5)	43 (67.2)	72 (54.1)	32 (56.1)	71 (68.9)	68 (68.7)	53 (49.5)	50 (48.5)
BPMed (Yes)	49 (40.2)	31 (48.4)	36 (27.1)	14 (24.6)	45 (43.7)	44 (44.4)	32 (29.9)	30 (29.1)
PA (Low)	10 (8.2)	3 (4.7)	11 (8.3)	1 (1.8)	9 (8.7)	8 (8.1)	8 (7.5)	6 (5.8)
	28 (23.0)	15 (23.4)	35 (26.3)	14 (24.6)	21 (20.4)	19 (19.2)	28 (26.2)	26 (25.2)

* Gender differences significant at p-value ≤ 0.01 for PBF and WC.

[†] Gender differences significant at p-value ≤ 0.01 for PBF and p-value < 0.05 for WC.

[‡] Gender differences significant at $p\text{-value} \leq 0.05$ for PBF (full sample only) and $p\text{-value} < 0.01$ for WC (full and reduced samples).

[§] Gender differences significant for PBF at $p\text{-value} \leq 0.05$ (full sample) and $p\text{-value} \leq 0.01$ (reduced sample) and $p\text{-value} < 0.05$ for WC (full and reduced samples).

Table 2
Results of Poisson regression of adult systolic (SBP) and diastolic (DBP) blood pressures against number of childhood measurements with high values of a) percent body fat (PBF), and b) waist circumference (WC)

Measurements from 122 men and 133 women were included in the analyses for PBF, while measurements from 103 men and 107 women were included in the analyses for WC. No other covariates were included in the analyses.

2a	PBF					
	Men			Women		
	Est	SE	p-val	Est	SE	p-val
SBP	0.03	0.007	<0.001	0.03	0.009	0.001
	Est	SE	p-val	Est	SE	p-val
DBP	0.02	0.007	<0.001	0.03	0.009	0.005
2b	WC					
	Men			Women		
	Est	SE	p-val	Est	SE	p-val
SBP	0.03	0.004	<0.001	-0.09	0.004	<0.001
	Est	SE	p-val	Est	SE	p-val
DBP	0.08	0.005	<0.001	-0.14	0.005	<0.001

Table 3

Results of multiple linear regressions of childhood percent body fat (cPBF) on systolic (SBP) and diastolic (DBP) blood pressures adjusted for a) adult lifestyle characteristics, and b) further adjusted by adult levels of percent body fat (aPBF)

Measurements from 64 men and 57 women were included in the analyses. Covariates for adult lifestyle characteristics include age, alcohol use (AL), smoking status (SM), level of physical activity (PA), and use of blood pressure medication (BPM). Not all covariates were included in final model (see Percent Body Fat portion of the Results Section; regression results not shown).

3a	SBP			DBP				
Men	Est	SE	p-value	Est	SE	p-value		
	cPBF	0.11	0.055	0.042	cPBF	0.10	0.043	0.026
	• Model includes AL, age and cPBF-age interaction			• Model includes AL, BPM, age and cPBF-age interaction				
Female	Est	SE	p-value	Est	SE	p-value		
	cPBF	0.11	0.048	0.027	cPBF	0.06	0.046	0.19
	• No other covariates included			• No other covariates included				
3b	SBP			DBP				
Men	Est	SE	p-value	Est	SE	p-value		
	cPBF	-0.09	0.071	0.22	cPBF	-0.09	0.050	0.11
	aPBF	0.61	0.265	0.027	aPBF	0.61	0.207	0.002
	• Model includes PA and cPBF-PA interaction			• Model also includes PA and BPM				
Female	Est	SE	p-value	Est	SE	p-value		
	cPBF	0.05	0.054	0.40	cPBF	0.05	0.055	0.55
	aPBF	0.49	0.181	0.009	aPBF	0.49	0.007	0.056
	• Model also includes age			• Model includes cPBF-aPBF interaction				

Table 4

Results of multiple linear regressions of childhood waist circumference (cWC) on systolic (SBP) and diastolic (DBP) blood pressures adjusted for a) adult lifestyle characteristics, and b) further adjusted by adult levels of waist circumference (aWC)

Measurements from 99 men and 103 women were included in the analyses. Covariates for adult lifestyle characteristics include age, alcohol use (AL), smoking status (SM), level of physical activity (PA), and use of blood pressure medication (BPM). Not all covariates were included in final model (see Waist Circumference portion of the Results Section; regression results not shown).

4a	SBP			DBP		
	Est	SE	p-value	Est	SE	p-value
Men						
	cWC 0.07	0.035	0.058	cWC 0.05	0.032	0.097
	• Model also includes AL			• Model also includes AL and age		
Female						
	cWC 0.04	0.035	0.22	cWC 0.03	0.032	0.35
	• Model also includes PA and age			• Model also includes PA		
4b	SBP			DBP		
	Est	SE	p-value	Est	SE	p-value
Men						
	cWC 0.05	0.035	0.13	cWC -0.03	0.029	0.36
	aWC 4.91	2.561	0.058	aWC 5.99	1.867	0.002
	• Model also includes AL and age			• Model also includes AL		
Female						
	cWC 0.02	0.032	0.53	cWC -0.01	0.027	0.62
	aWC 6.49	1.758	<0.001	aWC 6.07	1.421	<0.001
	• Model also includes age			• No other covariates included		