Adult stature is an important factor in a number of reproductive and non-reproductive health problems, including perinatal mortality, low birthweight, overall mortality and cardiovascular mortality, coronary disease, and type 2 diabetes mellitus. Both adult stature and birthweight interact to confer risk for hypertension.

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It is known that there can be both secular increases and decreases in adult stature, depending on the changing socio-economic status (SES) circumstances of a population. Economists who refer to themselves as anthropometric historians, view stature as a surrogate for nutrition and the standard of living, and seek relationships of secular trends of stature with existing social and economic conditions in order to better understand the effects of governmental policies and environmental conditions on the health and well-being of populations. However, with some exceptions, evidence for secular trends in stature is documented by cross-sectional and convenience samples, usually of male subpopulations, often military or convicts, occasionally also indigent female parturients. There is little information on intergenerational associations of lineal relatives of either gender, which may give
more important information. In this study we compare how maternal grandmother’s stature, mother’s birthweight, and several socio-economic variables relate to mothers’ adult stature in an intergenerational cohort of four ethnic groups.18 The specific study of intergenerational associations of female growth is also particularly relevant, since the contribution of the mother’s birthweight and stature, which are also interrelated to fetal growth, is greater than that of the father,19–21 and since both birth size and postnatal growth and stature are related to some non-reproductive health problems.10,11 The study of the intergenerational relationships of prenatal and postnatal growth continues to be important. We link available measures of growth of females in two generations.

Methods
The study base
The Washington State Intergenerational Cohort was derived from several statewide data sources. The Washington State Department of Health each year links the live birth/infant death/fetal death file with the computerized hospital discharge summaries of all obstetric and neonatal admissions. We further linked these to data from the birth certificates of their mothers who were born in the state, 1949 and later, when birthweight was on the birth certificate.18

We later linked parents and grandparents to the Washington State driver’s license database to obtain their self-reported heights, recorded in inches. Linkage was accomplished for 72.2% of mothers and 42.1% of grandmothers. It was possible to compare the self-reported heights to measured heights of 480 control women of childbearing age from another study. The mean difference, measured to self-reported, was 0.1 in. (0.28 cm), with a correlation coefficient of 0.95.22

In order to select study samples which could be used for various studies, we used maternal grandmother/mother/infant triads, even though infant outcomes are not a crucial part of this particular study. In this study this amounted to the following proportions of all births in the cohort: non-Hispanic Whites, 37.0%; African Americans, 27.7%; Native Americans, 27.5%; Hispanics, 22.8%. The mothers were born in 1949–1979, and the births occurred in 1987–1995. Only mothers and infants who were singletons were included, and infant deaths were excluded. Mothers of infants of both genders were included.

The variables
There was sparse information on the birth certificates before 1968, the years when almost half of the mothers in this cohort were born, and in Washington State parental education was not added until 1992. Therefore, only a small number of SES variables considered to possibly be in the causal pathway for mothers’ stature are available on the birth certificates of mothers and infants which yielded sufficient numbers for analysis. The only SES variables on the mother’s birth certificate referable to the grandmother were the following: age and parity, treated continuously, and grandmothers’ marital status, single/married. A variable obtained from the infants’ birth certificates was mother’s age, treated as a continuous variable. Grandmother’s and mother’s stature were obtained from the driver’s license records. Stature is treated as a continuous variable, expressed in inches, since these were recorded as whole inches.

Statistical methods
We first calculated a correlation matrix including each of the predictor variables and the dependent variable of interest—mother’s stature (available as Supplementary Data at IJE Online). We then compared the simple correlation coefficients with the partial correlation coefficients related to maternal stature. After this we performed multiple correlation analysis. Partial correlation coefficients estimate the proportion of variance of the dependent variable attributed to a single predictor variable after the variance from other predictor variables are accounted for. Tests of significance were based on the appropriate partial correlation coefficient, $t$ test, and corresponding $P$-value. We generated multiple correlation coefficients ($R^2$) to describe the overall proportion of variation of the dependent variable attributed to all of the independent variables included in the equation. The four SES variables were all included in a single analysis. Because each had low predictive value compared with each of the growth measures, there was no advantage to estimating their individual contributions. With maternal stature as the dependent variable we successively added grandmaternal stature, mothers’ birthweight, and the combined SES variables, and compared the $R^2$ values of the various correlation models. Each ethnic group was analysed separately. All analyses were performed with STATA programs.23

Results
Characteristics of the samples
The comparisons of the study samples with those excluded because of missing data points are presented in Table 1. There is a remarkable intergenerational increase in non-marital childbearing ($P < 0.001$). Compared with those excluded, the study samples had higher mean mothers’ birthweight except for the Hispanics, which suggests that the analytical samples were of slightly lower risk. Further, compared with the other ethnic groups, the Whites had fewer mothers and grandmothers who were teenaged or unmarried, and fewer mothers who were of low birthweight. African Americans had the highest prevalence of maternal and infant low birthweight, and the lowest mean maternal birthweights. In all ethnic groups, mothers were statistically significantly taller than the grandmothers ($P < 0.0001$). In general, then, the SES variables of the included samples were of slightly lower risk than those excluded, with some differences among the four ethnic groups. This is consistent with the documentation that linkage to the drivers’ license database increased as educational attainment increased.22 Because our study samples were lower risk, the results were therefore more conservative and were likely to be biased towards the null.

Simple and partial correlations
The correlation matrix revealed that for each ethnic group, the four SES variables were inter-correlated, some positively and some negatively (available on line as Supplementary Data at IJE Online). The proportion of the variance of maternal stature accounted for by each of the SES variables (i.e. the partial $r$) was small compared with that of grandmother’s stature or mother’s birthweight (Table 2). Grandmother’s stature was the strongest predictor of maternal stature, mother’s birthweight was the next strongest predictor; and each was a stronger predictor of mother’s stature than any of the SES factors. We therefore then
Table 1 Comparing grandmaternal, maternal, and infant characteristics of the samples with those excluded because of missing values

<table>
<thead>
<tr>
<th></th>
<th>n = 8173 White</th>
<th>n = 1725 African American</th>
<th>n = 2049 Native American</th>
<th>n = 1470 Hispanic</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td><strong>A. Percentages of categorical variables</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grandmother single</td>
<td>2.63</td>
<td>3.94*</td>
<td>31.48</td>
<td>32.99</td>
</tr>
<tr>
<td>Grandmother nullipara</td>
<td>29.35</td>
<td>31.84*</td>
<td>35.36</td>
<td>34.98</td>
</tr>
<tr>
<td>Grandmother &lt;20 years</td>
<td>11.94</td>
<td>16.69*</td>
<td>25.22</td>
<td>31.15*</td>
</tr>
<tr>
<td>Mother single</td>
<td>18.45</td>
<td>27.52*</td>
<td>72.64</td>
<td>70.27</td>
</tr>
<tr>
<td>Mother nullipara</td>
<td>45.90</td>
<td>42.59*</td>
<td>51.59</td>
<td>41.92*</td>
</tr>
<tr>
<td>Mother &lt;20 years</td>
<td>9.76</td>
<td>12.51*</td>
<td>32.75</td>
<td>26.21*</td>
</tr>
<tr>
<td>Mother smoked</td>
<td>19.23</td>
<td>26.84*</td>
<td>22.84</td>
<td>29.19*</td>
</tr>
<tr>
<td>Maternal LBWa</td>
<td>4.67</td>
<td>5.81*</td>
<td>10.09</td>
<td>11.39</td>
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**B. Means of continuous variables**

<table>
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<th>n = 2049 Native American</th>
<th>n = 1470 Hispanic</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>Included</td>
<td>Excluded</td>
<td>Included</td>
<td>Excluded</td>
</tr>
<tr>
<td>Grandmother's stature (in.)</td>
<td>64.31</td>
<td>64.29</td>
<td>64.46</td>
<td>64.39</td>
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<tr>
<td>Grandmother's age</td>
<td>25.57</td>
<td>25.08*</td>
<td>24.17</td>
<td>24.03</td>
</tr>
<tr>
<td>Mother's birthweight (g)</td>
<td>3325</td>
<td>3286*</td>
<td>3129</td>
<td>3093*</td>
</tr>
<tr>
<td>Mother's stature (in.)</td>
<td>65.04</td>
<td>64.98</td>
<td>64.94</td>
<td>64.81</td>
</tr>
<tr>
<td>Mother's age</td>
<td>26.39</td>
<td>26.51</td>
<td>22.62</td>
<td>23.93*</td>
</tr>
</tbody>
</table>

*P < 0.05; *P < 0.01; **P < 0.001.

Table 2 Simple and partial correlation coefficients of grandmaternal and maternal growth and socio-economic status (SES) variables predicting mother's stature

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<thead>
<tr>
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<th>n = 8173 White</th>
<th>n = 1725 African American</th>
<th>n = 2049 Native American</th>
<th>n = 1470 Hispanic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>Partial r</td>
<td>r</td>
<td>Partial r</td>
</tr>
<tr>
<td>Grandmother's stature</td>
<td>0.4360*</td>
<td>0.4144*</td>
<td>0.3980*</td>
<td>0.3854*</td>
</tr>
<tr>
<td>Mother's birthweight</td>
<td>0.2529*</td>
<td>0.2155*</td>
<td>0.2624*</td>
<td>0.2420*</td>
</tr>
<tr>
<td>Grandmother's age</td>
<td>0.0154</td>
<td>0.0545*</td>
<td>0.0336</td>
<td>0.0403</td>
</tr>
<tr>
<td>Grandmothers single</td>
<td>-0.0225*</td>
<td>-0.0621*</td>
<td>0.0254</td>
<td>0.0492*</td>
</tr>
<tr>
<td>Grandmoth. parity</td>
<td>-0.0388*</td>
<td>-0.0635*</td>
<td>0.0015</td>
<td>-0.0380</td>
</tr>
<tr>
<td>Mother's age</td>
<td>0.0311*</td>
<td>0.0176</td>
<td>0.0098</td>
<td>0.0231</td>
</tr>
</tbody>
</table>

*P < 0.05; *P < 0.01; **P < 0.001.

treated the SES variables in combination in the multiple correlation analysis below.

**Multiple correlation analysis**

Table 3 shows that when mother’s birthweight was added to grandmother's stature the multiple R² values increased across all four ethnic groups. These two growth measures together had R² values between 0.17 and 0.26. The addition of all the SES variables increased the R² values minimally in the four ethnic groups. The combined SES measures have very small R² values, 0.0013–0.025, but are statistically significant, except for the African Americans.

**Discussion**

Numerous studies document the direct relation of maternal adult stature to infant birthweight, but the intergenerational influence of how people grow needs to be further elucidated.

Most information on secular changes in adult stature is based on cross-sectional studies of convenience samples, often of male military or prison origin. The importance of studying female intergenerational growth per se is highlighted by the fact that the mother's growth is a much stronger determinant of infant birth size, which in turn is related to the risk of both reproductive and non-reproductive health problems later in life. This study longitudinally linked grandmother's stature to mother's (i.e. her daughter) birthweight and adult stature.

We found that mother's stature is partly determined by her own mother's stature (i.e. the maternal grandmother), and partly by her own birthweight. The importance of maternal birthweight to the birth size of the next generation of infants birthweight, gestational duration, and relative intrauterine growth, has also been documented elsewhere.
Table 3: Multiple correlation ($R^2$) models of grandmaternal and maternal growth and socio-economic status (SES) variables as predictors of mother's stature

<table>
<thead>
<tr>
<th></th>
<th>White</th>
<th>African American</th>
<th>Native American</th>
<th>Hispanic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n = 8173$</td>
<td>$n = 1725$</td>
<td>$n = 2049$</td>
<td>$n = 1470$</td>
</tr>
<tr>
<td>Grandmother's stature</td>
<td>0.1901*</td>
<td>0.1584*</td>
<td>0.1362*</td>
<td>0.2170*</td>
</tr>
<tr>
<td>Grandmother's stature</td>
<td>0.2264*</td>
<td>0.2064*</td>
<td>0.1717*</td>
<td>0.2575*</td>
</tr>
<tr>
<td>$R^2$ increase</td>
<td>0.0363</td>
<td>0.0480</td>
<td>0.0355</td>
<td>0.0405</td>
</tr>
<tr>
<td>Grandmother's parity, marital status and age; and mother's age</td>
<td>0.2304*</td>
<td>0.2081*</td>
<td>0.1760*</td>
<td>0.2763*</td>
</tr>
<tr>
<td>$R^2$ increase</td>
<td>0.0040</td>
<td>0.0017</td>
<td>0.0043</td>
<td>0.0188</td>
</tr>
<tr>
<td>Grandmother's parity, marital status and age; and mother's age</td>
<td>0.0048*</td>
<td>0.0013</td>
<td>0.0040*</td>
<td>0.0248*</td>
</tr>
</tbody>
</table>

*P < 0.05, **P < 0.01, ***P < 0.001.

Grandmother’s stature and mother’s birthweight are individually stronger predictors of mother’s adult stature than are each of several available SES measures considered individually or together: grandmother’s age, parity and marital status, and mother’s age. These findings are similar to those from a British population-based cohort, where the increase in stature, mothers to daughters and fathers to sons, was related to both the stature and birthweight percentile for gestational week, or birthweights of the parents. We did not have sufficient data on gestational duration to deal with mothers’ birthweight percentile. The importance of fathers’ growth in that study illustrates the importance of genetic factors, which are beyond the scope of the current study.

We also found that the SES variables available to us did not much alter the associations between the two background growth variables, grandmother’s stature and mother’s birthweight, with mother’s stature. The British study found some quantitative differences in the intergenerational increase in stature in the several social class groups, but the pattern of increases was the same.17 The previous study of our same intergenerational cohort showed that the strength of prediction of maternal growth variables (mother’s birthweight, adult stature, prepregnant weight) for infant birthweight similarly was not increased much by any or all SES variables (mother’s age, parity, educational attainment, marital status, or month of onset of prenatal care).24 This is consistent with the usual finding that the influence of maternal birthweight on pregnancy outcome persists after adjustment for SES factors.18,25,26 Similarly, others have found that the association of stature with chronic diseases persisted after adjustment for SES factors.27 This is of importance, since much of the literature on early life factors in adult chronic diseases, is based on samples for which there is little information about socio-economic characteristics. These studies have been criticized for that reason.28 We speculate that associations of birth size and adult stature with chronic diseases may also be little altered by adjustments for SES factors, and that it is the growth status of the individual that is more important than the socio-economic circumstances. At the same time, it should be realized that an individual’s growth status was determined in part by the socio-economic conditions of the family of upbringing.2,5,19,29

In our two studies and in the British study17 there is an additional lesson. There is no doubt that socio-economic circumstances influence both prenatal and postnatal growth.2,5,19,20,29 The British study,17 and our previous study24 and this one, help to clarify the relative importance of socio-economic factors at the various phases of growth. For instance, because grandmother’s stature is a strong predictor of mother’s birthweight, and because mother’s birthweight is a strong predictor of infant’s birth size,18,20,24 potentially environmentally altered influences on infant’s prenatal growth are already established before the infant is conceived or born, something suggested previously.30

In this study grandmother’s growth was a stronger predictor of mother’s growth, and in the previous study24 mother’s growth was a stronger predictor of infant’s prenatal growth, than were the available SES variables. At the same time, grandmother’s SES variables are associated with mother’s birthweight, and mother’s SES variables are associated with infant birthweight (Supplementary Data available online on line at UJE Online). Thus we can tentatively conclude that the importance of socio-economic factors to human growth is greater relative to the growth of the mother than to the prenatal growth of the infant.

The associations between maternal birthweight and adult stature with reproductive health have been repeatedly demonstrated over the last several decades.18–20 In other studies of our intergenerational cohort associations of mother’s birthweight were found with infant low birthweight and preterm birth,18 and with gestational diabetes mellitus,31 respiratory distress syndrome,32 and the risk for cesarean section,33 with some differences among the ethnic groups. The associations between stature and such problems as coronary disease,7,8 and overall cardiovascular mortality,5 also date back several decades. More recently, stature has been found to be inversely related to type 2 diabetes mellitus.9 Associations with these same chronic diseases have also been found with birthweight,32 and both birthweight and stature interact to influence hypertension.10,11 Thus how people grow partly determines a number of health problems. At the same time, both acute and chronic diseases, as well as nutrition, stress, and other factors can interfere with the postnatal growth process, and socio-economic status is also related to prenatal and postnatal growth, and thus to stature.19 Therefore the intergenerational growth process needs to be further explored.

While the grandmaternal SES variables probably did not completely delineate those conditions which might influence growth, there is suggestive evidence of their utility. For instance, childhood growth has been related to both parity and sibship size, independent of social class,29 and sibship size has been related to adult stature.34 Young maternal age35 and the unmarried state36 have been related to suboptimal child care, and thus possibly to the child’s postnatal growth. Age is certainly related to growth, so on the basis of many previous studies and the Camden studies37,38 young grandmother’s age would be expected to influence mother’s prenatal growth and subsequently also mother’s stature. Mothers born to unmarried
grandmothers had reduced birthweight (Supplementary Data at IJE Online), which in turn is expected to influence postnatal growth and stature. Lower SES is related to earlier onset of childbearing and higher parity, while higher SES is related to later onset of childbearing and lower parity.\(^\text{44-47}\) In this study and elsewhere non-marital childbearing was related to lower educational attainment (Supplementary Data available at IJE Online). Thus, the available grandmothers’ SES variables probably indirectly influenced the growth of their daughters—the mothers in this cohort.

Even though grandmother’s stature and mother’s birthweight are correlated, each independently relates to mother’s stature, as is shown by both the partial correlation analysis and the multiple correlation analysis.

In spite of large differences in the prenatal growth of Whites and African Americans, as shown here and elsewhere,\(^\text{39}\) and the generally lower socioeconomic circumstances of African Americans today and historically, African American postnatal growth is very similar to that of Whites. In our cohort African American grandmothers’ and mothers’ statures are equal to or greater than those of the other three ethnic groups. At the same time, African American mean mother’s birthweight and female infant birthweight are smaller, and the proportions of maternal and female infant low birthweight are greater than those of the other three ethnic groups.\(^\text{24}\) Thus there is a disassociation between African American prenatal and postnatal growth. We speculate that this disassociation is somehow partly a result of historical intergenerational deprivation experienced by this ethnic group. This together with the fact that in our cohort the stature of African American mothers is less influenced by socioeconomic factors than those of the other three ethnic groups indicates that African American growth is inherently unique. These differences are probably partly influenced by genetic factors, and warrant further investigation.

The frequent restriction of some growth studies, e.g. of prenatal growth, to evaluating only socioeconomic factors, we suggest, may be of limited value for some purposes. Put another way, growth relates to growth from one generation to the next.

**Strengths and limitations**

The major strength of this study is that we were able to evaluate the relative strength of prediction of growth measures and socioeconomic factors for intergenerational female growth. We did this separately for four major American race/ethnic groups. While the samples used in this study were derived from a population-based intergenerational database, it was not possible to use the entire database because of missing data for some grandmother/mother pairs. The samples in each ethnic group were of slightly lower socioeconomic risk than those excluded from analysis because of missing data. However, the qualitative consistency along with small quantitative differences in results in the four ethnic groups suggests that the pattern of comparative strength of growth measures and socioeconomic measures for the prediction for mother’s stature will be similar in the general population. Mother’s education was not available for sufficient numbers of cases to analyse. However, the weakness of the socioeconomic variables compared with growth variables is similar to our previous study of maternal growth variables and socioeconomic factors as predictors of infant birthweight.\(^\text{24}\)

**Conclusions**

Mother’s stature is determined partly by her mother’s stature and by her own birthweight. These associations with mother’s stature are stronger individually than the associations with several grandmaternal and maternal socioeconomic factors considered individually or together. Since in this intergenerational cohort\(^\text{24}\) and a number of other studies, mother’s stature has been found to influence infant birthweight, our results offer further support for the concept that some birth outcomes are in part the result of an intergenerational growth process involving female linear relatives: grandmothers, mothers, and female infants at each stage of their development. Thus some potentially modifiable determinants of some birth outcomes are already established even before a mother is conceived or born, as well as by the time a pregnancy occurs.\(^\text{30}\)

Put another way: ’It seems that good growth means good health and good health means good growth, and it appears that the quality of growth is both a cause and a consequence of the health status of individuals and populations’.\(^\text{20}\) We speculate that the importance of socioeconomic factors may relate more to the previous growth of mothers than to the growth of their infants. That there were similar findings in four race/ethnic groups—non-Hispanic Whites, African Americans, Native Americans, Hispanics—suggests that similar patterns of associations will be seen in the general population.

Because it is now established that both birthweight and adult stature are related to several perinatal problems and adult chronic diseases, further elucidation of the multigenerational prenatal and postnatal growth process will have broad relevance.

**Acknowledgements**

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**KEY MESSAGES**

- Maternal grandmother’s stature is a determinant of mother’s birthweight and mother’s stature.
- These three measures are in the causal pathway for some birth outcomes.
- Thus some determinants of some birth outcomes are established before a woman’s pregnancy begins.
- This highlights the intergenerational contribution to a woman’s reproductive success.
References


