# Size at Birth and Gestational Age as Predictors of Adult Height and Weight

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**Background:** Both birth length and birth weight are associated with height in adulthood and may have independent contributions to adult body size, but the effects of gestational age on these associations have not been fully evaluated. Our objective was to examine the independent contributions of gestational age, and of length and weight at birth, on adult (age 18 years) height and weight, with a special focus on the effects of being born preterm.

**Methods:** In this nationwide cohort study, records of 348,706 male infants included in the Medical Birth Registry of Norway (1967–1979) were linked to the Norwegian Conscripts Service (1984–1999). Complete follow-up information, including deaths, emigration, and disability pension, was obtained for 94%. We analyzed length and weight at birth using standardized (z-scores) values and stratified by gestational age.

**Results:** The positive association between birth length and adult height was stronger than between birth weight and adult weight ($R^2$ = 7–9% compared with <0.1%, respectively). The strongest associations were seen among those born at gestational age 39 to 41 weeks. The effects of birth length on adult height, and of birth weight on adult weight, were considerably less among preterm births than among term births. Length and weight at birth each contributed independently to adult stature and body weight. The increase in adult weight per relative birth weight category was greatest for infants who were both heavy and long at birth.

**Conclusions:** Birth length is perhaps a better predictor of adult height and weight than birth weight, and should be considered as a possible risk factor for adult morbidity and mortality.

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It is not clear whether adult height is programmed by events in utero.[1] Little is known about the underlying genetics of adult stature,[2] and the relative contributions of genetics, fetal growth, and childhood environmental factors to adult stature are also unknown.[3] Both birth weight[4–7] and birth length[1,4–10] are associated with height in adulthood. Low birth weight is associated with an increased risk of health problems, including cardiovascular disease and diabetes—findings that have led to the fetal programming hypothesis.[11]

It seems to be generally accepted that birth length is more important than birth weight in predicting adult height.[4,6–10] It is less clear, however, whether birth length predicts adult height independently of gestational age. Previous studies have had limited ability to explore the effects of preterm delivery as a result of small sample sizes and thus few preterm infants.[7–9]

Most previous studies have focused on the effects on adult size of being small-for-gestational age[6,7,9,10,12] or of various indices of birth length and weight. However, these are composite measures that do not take advantage of the full variation of the initial registrations of birth weight and length and of gestational age. In addition, statistical adjustments for highly intercorrelated variables such as anthropometric measures and gestational age have typically been made by regression modeling[7,8,12,13] or by stratification in broad categories.

Because length, weight, and gestational age at birth may have independent contributions to adult body size, it is useful to examine each by itself, as well as to determine possible interactions between them. In this nationwide study, we examined gestational age, and length and weight at birth as predictors of height and weight at 18 years of age. In particular, the very large sample made it possible to study the effects of being born preterm. We linked data from 4 national registries, facilitating nearly complete follow up.

## METHODS

Since 1967, the Medical Birth Registry of Norway has collected data on all births from 16 weeks of gestation. Weight, length, and gestational age at birth are recorded by a midwife according to standardized procedures. From 1967 through 1979, 393,570 singleton live-born infant boys were registered. Data on all deaths registered by Statistics Norway are routinely linked to the birth records. For the present study, we performed record linkages between the Medical Birth Registry, Statistics Norway including data on all deaths, the National Health Insurance Office, and the National Conscript Service. The birth cohorts of 1967–1979 were traced through 1999.

Among the 393,570 male live births, 4833 (1.2%) died before age 1, 3550 (0.9%) died between age 1 and military draft, and 3788 (1.0%) emigrated. Norwegian men are required to register with the draft board at 18 years of age for physical and mental examinations. Those registered in the National Health Insurance Office as being permanently disabled are exempted. In the birth cohorts included here, 5692 (1.4%) had at least 1 *International Classification of Diseases*, Ninth Revision diagnosis indicating disability as a result of chronic disease or birth defects. Another 24,355 (6.2%) never appeared before the draft board for various reasons, including having a foreign citizenship. Altogether, 351,352 (89.3%) male conscripts with draft board medical information were identified in the Norwegian Conscripts Service during the period 1984 to 1999. Information at the draft board was collected under the supervision of healthcare personnel.

Birth weight, birth length, gestational age, maternal age, parity, and marital status were obtained from the Medical Birth Registry, and adult weight and height from the Conscripts Service. Birth weight data were missing for 657 births (0.17% of the total birth cohort) and length data were missing for 4801 births (1.2%).[14] Gestational age was estimated from the reported last menstrual period and analyzed as completed weeks of gestation. Gestational age was missing for 13,544 births (3.4% of the total birth cohort). Additionally, 3194 infants (0.8%) with z-scores of birth weight by gestational age outside 3 standard deviations were excluded in all analyses of gestational age.[15] Information on parity was missing for 471 births and on marital status for 547 mothers, whereas data on maternal age were complete.

Analyses were restricted to conscripts with measurements of both weight and height. This excluded 2646 men, leaving for analysis a total of 348,706 in the study cohort (89% of the total birth cohort).

The study was cleared by the Regional Committee for Medical Research Ethics Review and approved by the Norwegian Board of Health and the Data Inspectorate.

### Statistical Methods

Birth length was analyzed in categories of whole centimeters, and stratified by gestational age and birth weight. Birth weight was categorized as <1000 g, 1000–4999 g (in 250-g, 500-g, or 1000-g categories), and ≥5000 g, and stratified by gestational age and birth length. We defined gestational age less than 37 weeks as preterm (26–33 weeks as early preterm and 34–36 weeks as moderately preterm), 37–41 weeks as term, and 42–44 weeks as postterm.

The distributions of birth length and weight are both approximately bell-shaped and shifted toward lower values by decreasing gestational age (Fig. 1). Therefore, the different distributions of birth length should not be compared without standardizing for gestational age. Likewise, birth weight should also be standardized within weeks of gestational age.[16] We performed separate standardizations for birth length and weight within weeks of gestational age using z-scores (standard deviations [SD] above or below the mean) calculated by subtracting the calculated mean from the observed value and dividing by the SD. For births with gestational age 39–41 weeks, further standardization was done on birth length within 4 categories of birth weight (<3000 g, 3000–3499 g, 3500–3999 g, and ≥4000 g) and on birth weight within 5 categories of birth length (≤48 cm, 49 cm, 50 cm, 51 cm, and ≥52 cm).

Analysis of variance and linear regression analysis were used for the calculation of regression coefficients. We calculated $R^2$ to quantify the variance in adult height and weight explained by length and weight at birth.

## RESULTS

Mean length, weight, gestational age, and ponderal index (birth weight [kg]/birth length [$m^3$]) of the live-born infant boys are presented in Table 1. Mean birth weight among those who died during infancy was 1241 g less than in the group that was later drafted, whereas those who became disabled weighed on average 186 g less than the drafted group. Boys who later emigrated weighed 68 g less than the drafted group, whereas the untraceable group did not differ in birth weight from the drafted group.

In the total birth cohort 19,975 (5.3%) were born preterm. In the preterm birth group, 11.2% died in infancy, 1.1% died after age 1, 1.0% emigrated later, 2.4% became disabled and were never drafted, 5.6% were untraceable, and 78.7% appeared before the draft board. Among those drafted, mean age was 18.7 (± 0.7) years, mean height 179.9 (± 6.5) cm, mean weight 72.3 (± 11.4) kg, and mean body mass index (weight [kg]/height [$m^2$]) 22.3 (± 3.1). A total of 15,454 (4.5%) were born preterm.

Table 2 presents mean adult height and weight by maternal characteristics, gestational age, birth length, and birth weight among the 348,706 men comprising the study cohort.

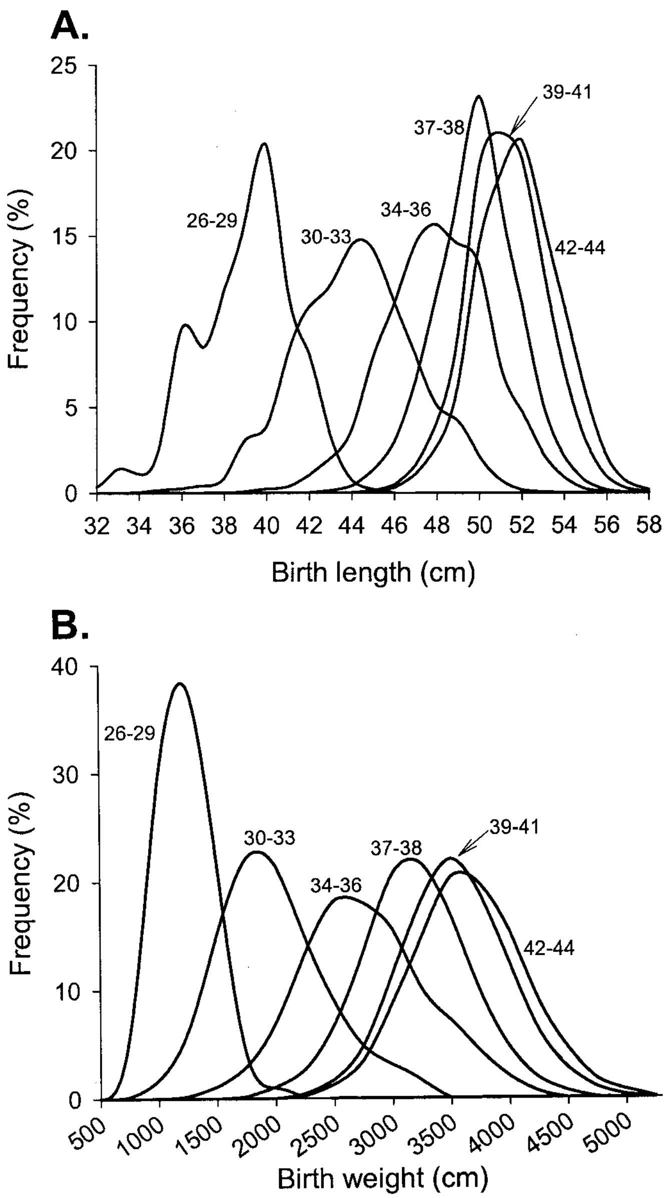


**FIGURE 1.** Distributions of (A) birth length and (B) birth weight by 6 categories of gestational age (weeks) (n = 348,706 male infants).

## Birth Length and Adult Height

Mean height at conscription increased linearly by increasing birth length from 46 cm (Fig. 2A). Birth lengths below 46 cm were only weakly associated with adult height. Because these short lengths represented mainly preterm births (Fig. 1A), we evaluated the effect of birth length on adult height in strata of gestational age (Fig. 2B, C). Within each stratum, adult height increased linearly with increasing birth length. When absolute birth lengths were used (Fig. 2B), the impression was that infants born at 26–36 weeks of gestation were taller as adults when compared with infants of the same length who were born at 37 weeks or later.

When birth lengths were standardized to a z-scale (with means set to zero and SD to 1) (Fig. 2C), the 6 gestational age curves were shifted. The gestational age curves for 37–38, 39–41, and 42–44 weeks were overlaid (ie, through the whole range of z-scores for birth length, term and post-term infants reached approximately the same adult height). For gestational ages 26–29, 30–33, and 34–36 weeks, the relatively short infants became similar height adults as the term and postterms, whereas the relatively long infants became shorter adults as compared with same-length infants born at term. For instance, at birth length +2 SD, infants born at 30–33 weeks became on the average 5 cm shorter than infants born at term.

The strongest association between birth length and adult height was seen among those born at gestational age 39–41 weeks; the regression coefficient ($\beta$) for standardized birth length on adult height was 2.54 (standard error [SE] = 0.01) per SD, corresponding to a 15.2-cm difference in adult height when birth length varied from −3 to +3 SD (ie, from 45–57 cm on the absolute scale). The relation between birth length and adult stature was weaker for preterm as compared with term births, particularly for those with birth lengths above the mean ($P < 0.0005$ for interaction).

To examine whether birth length influenced final height independently of birth weight and gestational age, birth length was standardized within 4 strata of birth weight (Fig. 3D). We restricted the analyses to gestational age 39–41 weeks. The effect of birth length on final height was reduced when stratifying for birth weight, as judged by the difference in change of slopes between Figures 2C and 2D ($\beta$ was reduced from 2.54 [SE = 0.01] to 1.86 [0.01] cm per SD unit). Heavier infants became taller than low-weight infants, adding to the positive effect of higher relative birth length. For example, for the same relative birth length, adult height increased 1.86 cm for 1-SD unit (1.32 cm) increase in relative birth length, and approximately 2 cm by adding 500 g to birth weight. The inclusion of maternal age, parity, and marital status in the regression model did not change the association between birth length and adult height. The $R^2$ coefficient varied between 7% and 9% for the 4 strata in Figure 2D; in other words, 7% to 9% of the variation of adult height could be explained by birth length. Birth weight and length together explained 15% of the variation in adult height.

## Birth Weight and Adult Weight

Figure 3A illustrates the positive association between birth weight and adult weight, with a clear linear relation for birth weights above 2500 g but not for lighter infants. Like with the short babies, these low-weight babies represent the births of shorter gestation (Fig. 1B). When birth weight and adult weight were stratified within categories of gestational

**TABLE 1.** Mean Length, Weight, Ponderal Index, and Gestational Age for 393,570 Male Infants Within the Birth Cohorts 1967–1979, Medical Birth Registry of Norway, for the Different Subgroups of Boys Who Were Never Drafted, and for Those Drafted at the Norwegian Conscript Service, 1984–1999

| | No. of Infants | Birth Length (cm) Mean ± SD | Birth Weight (g) Mean ± SD | Ponderal Index* Mean ± SD | Gestational Age (wks) Mean ± SD |
|---|---|---|---|---|---|
| Total birth cohort | 393,570 | 50.9 ± 2.4 | 3563 ± 567 | 26.4 ± 2.4 | 39.8 ± 2.1 |
| Dead before age 1 | 4833 | 45.1 ± 6.6 | 2341 ± 1106 | 24.3 ± 3.8 | 35.0 ± 5.8 |
| Dead between age 1 and military draft | 3550 | 50.7 ± 2.6 | 3501 ± 594 | 26.2 ± 2.5 | 39.7 ± 2.3 |
| Emigrated before military draft | 3788 | 50.6 ± 2.3 | 3514 ± 538 | 26.4 ± 2.3 | 39.8 ± 2.1 |
| Disabled and not drafted | 5692 | 50.2 ± 3.0 | 3396 ± 665 | 26.1 ± 2.7 | 39.5 ± 2.6 |
| Untraceable | 24,355 | 50.9 ± 2.3 | 3577 ± 539 | 26.4 ± 2.4 | 39.9 ± 2.0 |
| Drafted | 351,352 | 51.0 ± 2.3 | 3582 ± 539 | 26.4 ± 2.4 | 39.9 ± 1.9 |

*Ponderal index = birth weight (kg)/birth length ($m^3$).

age, adult weight increased linearly with increasing birth weight (Fig. 3B, C). Infants born at 26–38 weeks became heavier adults as compared with infants born at 39 weeks or later, given the same absolute weight at birth (Fig. 3B). However, when evaluating the effect of relative birth weight on adult weight, the gestational age curves shifted (Fig. 3C). For each relative birth weight, term and postterm infants attained the same adult weight. Preterm infants were lighter as adults through the whole range of z-scores for birth weight compared with those born at term. The regression coefficient ($\beta$) for birth weight on adult weight was strongest for gestational age 39–41 weeks (1.42 [SE = 0.03]).

When births with gestational age 39–41 weeks were stratified for 5 birth length categories (Fig. 3D), the effect of birth weight on adult weight was stronger for longer infants than for shorter. The regression coefficients for infants with lengths ≥52 cm, 51 cm, 50 cm, 49 cm, and ≤48 cm were 1.89 (SE = 0.04), 1.15 (0.06), 1.03 (0.06), 0.84 (0.09), and 0.80 (0.11), respectively. For infants ≤51 cm long, adult weight increased 0.8 to 1.15 kg by 1-SD unit (326 g) increase in relative birth weight. Adult weight increased in the range 2 to 4 kg by adding 2 cm to birth length for the same relative birth weight. For the longest infants (≥52 cm), adult weight increased 1.89 kg per 1-SD unit increase in relative birth weight (ie, 10.4 kg in the range −2.5 SD to 3 SD). Comparing the trend for infants ≥52 cm with infants ≤51 cm, there was a strong interaction between birth weight and length on adult weight ($P$ <0.0001). Adjustment for maternal age, parity, and marital status did not change these results. For birth lengths ≤51 cm, less than 0.1% of the variation of adult weight could be explained by birth weight, compared with 2% among the longest infants. Birth length and weight together explained 4.6% of the variation in adult weight.

## DISCUSSION

Birth length is the most important predictor of both adult height and weight. This association was weaker among preterm babies, whereas preterm delivery itself was associated with lighter weight in adulthood. Length and weight at birth each contributed independently to final stature and body weight at 18 years of age, with long and heavy infants becoming particular heavy as adults.

Gestational age in our study was based on self-reported information about the last menstrual period. The birth registry did not record ultrasound dating during the period when our study infants were born, and no information on the accuracy of the reported menstrual dates is available. The residual births in the right tail of the birth weight distributions for gestational age groups 30–33 and 34–36 weeks (Fig. 1B) may represent infants for whom gestational age has been underestimated. These residuals[8–10] were estimated to be 15% for the distributions of 30–36 weeks and 3% for 39–41 weeks. After exclusion of the residual births for 30–36 weeks, the means and SDs for the 2 distributions were reduced, slightly influencing the z-scores. However, this did not alter the patterns presented in Figure 3C, particularly the finding that preterm infants attained a lower adult weight than term infants. Except for cases of anovulatory dysfunction, an extended follicular phase could increase the estimated gestational age by a few days only, and the effect on our findings would seem negligible.

It has been claimed that measurements of length at birth are less reliable than measurements of weight.[7] In our study, it is possible that birth length was overestimated in the groups comprising infant deaths and individuals who were disabled because of the higher proportions in these groups of infants with neonatal complications or malformations. For healthy newborns, however, any measurement error is assumed to be

**TABLE 2.** Mean Adult Height and Weight by Maternal Characteristics, Gestational Age, Length, and Weight at Birth Among the Cohort of 348,706 Male Infants, Medical Birth Registry of Norway, 1967–1979, Linked With the Norwegian Conscripts Service, 1984–1999

| | No. of Men | Adult Height (kg) Mean ± SD | Adult Weight (kg) Mean ± SD |
|---|---|---|---|
| Maternal age (years) | | | |
| ≤19 | 44,489 | 179.2 ± 6.4 | 72.3 ± 11.7 |
| 20–24 | 103,996 | 179.7 ± 6.5 | 72.2 ± 11.3 |
| 25–29 | 116,143 | 180.1 ± 6.5 | 72.3 ± 11.2 |
| 30–34 | 61,851 | 180.2 ± 6.5 | 72.5 ± 11.5 |
| 35–39 | 15,456 | 180.0 ± 6.6 | 72.5 ± 11.8 |
| ≥40 | 6770 | 179.8 ± 6.6 | 72.3 ± 12.0 |
| Parity* | | | |
| 0 | 141,782 | 180.0 ± 6.5 | 72.6 ± 11.4 |
| 1 | 116,634 | 179.9 ± 6.5 | 72.2 ± 11.2 |
| 2 | 55,911 | 179.8 ± 6.5 | 72.2 ± 11.4 |
| 3 | 21,267 | 179.6 ± 6.5 | 72.1 ± 11.7 |
| 4+ | 12,695 | 178.9 ± 6.6 | 71.7 ± 11.8 |
| Marital status | | | |
| Unmarried | 30,051 | 178.9 ± 6.5 | 72.5 ± 12.3 |
| Married | 318,187 | 180.0 ± 6.5 | 72.3 ± 11.3 |
| Gestational age (weeks) | | | |
| 26–29 | 468 | 178.3 ± 6.8 | 70.1 ± 10.8 |
| 30–33 | 2923 | 178.9 ± 6.6 | 71.3 ± 11.6 |
| 34–36 | 12,063 | 179.6 ± 6.6 | 72.2 ± 11.6 |
| 37–38 | 41,466 | 179.8 ± 6.6 | 72.3 ± 11.5 |
| 39–41 | 228,767 | 180.0 ± 6.5 | 72.3 ± 11.3 |
| 42–44 | 51,094 | 179.9 ± 6.5 | 72.6 ± 11.6 |
| Missing | 11,925 | 179.5 ± 6.6 | 72.3 ± 11.9 |
| Birth length (cm) | | | |
| ≤40 | 563 | 175.6 ± 7.1 | 67.5 ± 11.0 |
| 41–42 | 852 | 176.1 ± 6.7 | 68.4 ± 11.3 |
| 43–45 | 4552 | 176.1 ± 6.8 | 68.9 ± 11.6 |
| 46–48 | 32,245 | 176.2 ± 6.4 | 69.1 ± 11.2 |
| 49–51 | 164,431 | 178.8 ± 6.1 | 71.2 ± 11.0 |
| 52–54 | 126,654 | 181.9 ± 6.0 | 74.1 ± 11.3 |
| ≥55 | 15,522 | 185.2 ± 6.1 | 77.6 ± 11.4 |
| Missing | 3887 | 179.3 ± 6.7 | 73.2 ± 12.1 |
| Birth weight (g) | | | |
| <1000 | 35 | 173.3 ± 6.7 | 64.2 ± 11.3 |
| 1000–1999 | 2635 | 176.7 ± 6.8 | 68.6 ± 11.4 |
| 2000–2999 | 38,763 | 177.1 ± 6.5 | 69.2 ± 11.2 |
| 3000–3999 | 233,326 | 179.6 ± 6.3 | 71.8 ± 11.1 |
| 4000–4999 | 71,731 | 182.4 ± 6.2 | 75.5 ± 11.6 |
| ≥5000 | 1746 | 185.0 ± 6.4 | 80.5 ± 13.1 |
| Missing | 470 | 179.1 ± 7.0 | 72.7 ± 11.7 |

*Number of births, including stillbirths.

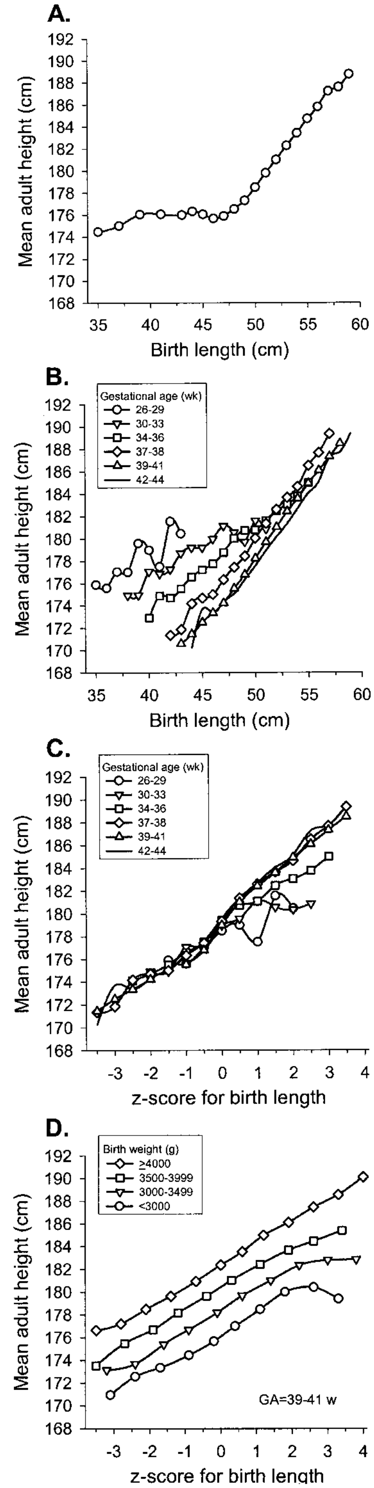


**FIGURE 2.** A, Mean adult height by birth length. B, Mean adult height by birth length, stratified by gestational age. C, Mean adult height by standardized birth length, stratified by gestational age. D, Mean adult height by standardized birth length for gestational age 39–41 weeks, stratified by birth weight (n = 348,706 male infants).

random with regard to final height. A challenge with regard to the analytical approach of birth length was the narrow range of values compared with the range of birth weight; 70% of the birth lengths were between 48 and 52 cm. Thus, although

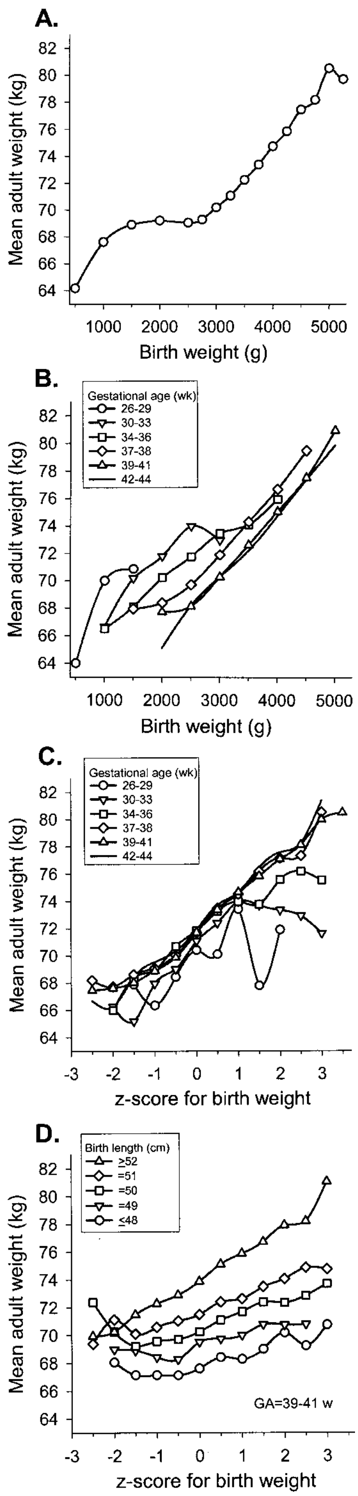


**FIGURE 3.** A, Mean adult weight by birth weight. B, Mean adult weight by birth weight, stratified by gestational age. C, Mean adult weight by standardized birth weight, stratified by gestational age. D, Mean adult weight by standardized birth weight for gestational age 39–41 weeks, stratified by birth length (n = 348,706 male infants).

birth length is recorded in centimeters, it is more like a discrete than continuous numerical variable.

Because birth length, birth weight, and gestational age are highly correlated variables, we have chosen to present relatively simple stratified analyses rather than regression analyses. Also, it has been suggested that stratified analysis is the preferable method for the evaluation of effect modification and in controlling for confounding.[17] Previous studies[4,5,8] have adjusted for gestational age and birth weight when evaluating the influence of birth length on adult height, thereby losing the opportunity to examine whether relations between size at birth and adulthood vary within different subgroups of gestational age. This standardization removes the effects on birth length or weight caused by differences in gestational age distribution. Our study shows that evaluation of the effects resulting from gestational age depends on the method of analysis. Our strategy involving stratification, as well as standardization, demonstrates the independent effects of birth weight and birth length on final height.

Most previous studies in this field have focused on the effects on adult size of various indices of birth length and weight[13] or of being small for gestational age.[6,7,9,10,12] Ponderal index is an expression of body weight relative to length; however, it does not differentiate between long and heavy versus short and thin. Although indices might be useful, their application could lead to a loss of important information about the relative contributions of length and weight as predictors of final height and weight.[18]

According to previous reports, birth length is strongly related to final height,[1,4,6–10] and birth weight is associated with both adult height[4,6–8] and adult weight.[4,7,9,13] However, previous studies[1,6–10,12] have had a limited ability to explore these associations among preterm infants. We found that adult weight is low among preterm infants compared with those born at term.

In the study by Leger et al.,[10] gestational age was not found to be predictive of final height; however, the study included only full-term subjects. Consistent with our findings, Tuvemo et al.[7] reported that short adult stature is associated with the birth characteristics short-for-gestational-age, light-for-gestational-age, or gestational age less than 32 weeks. For preterm infants, attained birth length or weight may have been influenced by complications in pregnancy leading to premature birth. Their smaller length is probably not the result of an intrinsic predisposition to shorter final height, but rather the result of factors associated with pregnancy outcome, including maternal diseases (eg, preeclampsia, premature rupture of membranes, and infections). For term births, the maturing process apparently has come to an end at delivery, because gestational age has little effect on final height and the most important predictor is birth length. Even for postterm infants in our study, the longer pregnancy did not add any further to an adult's growth potential compared with term deliveries.

Length and weight at birth each contributed independently both to adult stature and body weight. For adult height, the effects of birth length and birth weight were additive, suggesting that birth length and weight influence stature through different pathways. For adult weight, the combined effect of weight and length at birth was mainly additive, except for the strong interaction among the long infants (≥52 cm). Infants both heavy and long at birth became the heaviest adults, consistent with the findings of Rasmussen and Johansson.[13] For these large infants, growth may have been stimulated in utero (for example, if their mothers were diabetic or had excessive weight gain during pregnancy).

The relation between birth length and adult height was much stronger than the relation between birth weight and adult weight. Even if the overall $R^2$ of adult height explained by birth length was relatively small (7–9%), the contribution of birth weight to adult weight was even smaller (<0.1%). More striking is the finding that adult weight is much more strongly related to birth length than to birth weight. In term births, an additional 2 cm in birth length had a stronger effect on adult height and weight than an additional 500 g of birth weight. Although few studies have focused on infants' length at birth, Melve et al.[14] found that birth length is an important predictor of perinatal mortality, beyond the effect of birth weight. Low birth weight has been associated with the development of coronary heart disease, stroke, and diabetes.[11] Short stature in adulthood has been associated with an increased risk of health problems, especially cardiovascular disease.[1,2,7] Because birth length predicts adult stature, and adult stature is associated with disease, underlying shared factors (eg, birth length, final height, and adult disease) are likely. Heritability of stature is reported to be more than 80%.[2] Adult weight, however, affected by environmental factors is to a greater degree and appears to have a weaker hereditary component than does height. Thus, birth length may be a better predictor of adult health than birth weight.

In conclusion, our results confirm that birth length is a predictor of final height and that birth weight influences adult weight. Among term and postterm infants, final height and weight were independent of gestational age, probably because the maturing process of pregnancy has been completed. In preterm infants, the positive associations of length and weight at birth with adult height and weight were weaker, indicating that maternal or pregnancy-related factors may both influence a fetus' growth potential and initiate delivery. When using the entire range of length and weight at birth, both contributed independently to adult height and weight. Infants who were heavy and long at birth became the heaviest adults, and some of them may represent infants of mothers with diabetes or with excessive weight gain during pregnancy.

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