Very Low Birth Weight and Growth Into Adolescence

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Objective: To compare the growth and pubertal development of very low-birth-weight (VLBW) children (birth weight <1500 g) and normal-birth-weight (NBW) children (birth weight >2499 g) to adolescence to determine if, and at what age, VLBW children “catch up.”

Design: Inception cohort study to age 14 years.

Setting: Royal Women’s Hospital, Melbourne, Australia.

Patients: Eighty-six consecutive survivors with a birth weight less than 1000 g, 120 consecutive survivors with a birth weight of 1000 to 1499 g, and 60 randomly selected NBW controls. Children with cerebral palsy at age 14 years were excluded.

Main Outcome Measures: Weight, height, and head circumference measurements at birth and ages 2, 5, 8, and 14 years converted to \( z \) (SD) scores.

Results: At age 14 years, pubertal development was similar in NBW and VLBW children. At ages 2, 5, 8, and 14 years, VLBW children were significantly shorter and lighter and had smaller head circumferences than NBW children. The differences in height and weight between VLBW and NBW children were less apparent as SD scores improved in VLBW children over time. Within the VLBW group, compared with children with a birth weight of 1000 to 1499 g, those with a birth weight less than 1000 g had significantly lower weight \( z \) scores earlier in childhood but not at age 14 years, significantly lower height \( z \) scores only at age 2 years, and significantly lower head circumference \( z \) scores throughout childhood.

Conclusion: This group of VLBW children experienced late catch-up growth to age 14 years but remain smaller than their NBW peers.


Parents often ask how their very low-birth-weight (VLBW) child (birth weight <1500 g) will grow later in life, including into adulthood. The clinical impression is that VLBW children are often underweight and shorter than expected, even when corrected for gestational age, and this has been reported to occur early in childhood by several groups. There are some studies of catch-up growth in early childhood, but not all investigators have reported similarly. Growth data beyond the primary school years for VLBW children are sparse, and there are few other studies of growth in adolescence for complete cohorts of VLBW children born in the era of assisted ventilation. In these studies, pubertal development, which is associated with dramatic changes in growth, was not described, or the children were assessed early in puberty, or were stated to be postpubertal.

The aim of this study was to compare the growth of VLBW children and normal-birth-weight (NBW) children (birth weight >2499 g) at intervals to age 14 years to determine if, and at what age, VLBW children “catch up.” Secondary aims were to compare pubertal development between VLBW and NBW children and to determine whether growth differed between children with a birth weight less than 1000 g and those with a birth weight of 1000 to 1499 g.

Results: Follow-up rates at age 14 years were 92%, 83%, and 70% in children with a birth weight less than 1000 g, those with a birth weight of 1000 to 1499 g, and those with a NBW, respectively (Table 1). Of 45 children not seen by the research team at age 14 years, weight and height measurements were provided by the parents for 7 children but were not included because the accuracy of the measurements was unknown, and all but 2 VLBW and 3 NBW children had been measured at least once earlier in childhood. Thirteen children with cerebral palsy and 2 children seen at age 14 years but not measured were excluded (Table 1). Children without...
PARTICIPANTS AND METHODS

All participating children were born at Royal Women’s Hospital, a tertiary care referral hospital in Melbourne, Australia. There were 2 groups of preterm children and 1 group of term control children who survived to age 14 years. The first preterm group comprised 86 survivors from 258 consecutive extremely low-birth-weight (ELBW) children (birth weight <1000 g) born during a 63-month period from January 1, 1977, to March 31, 1982. The second preterm group comprised 120 survivors from 132 consecutive children with a birth weight of 1000 to 1499 g born in the last 18 months of the study. The 60 NBW children with birth weights greater than 2499 g were randomly selected from births in the last 6 months of the study; none of the NBW children died after discharge. Gestational age was determined from menstrual history and was confirmed, if possible, by ultrasound in early pregnancy. Growth data from these children earlier in childhood have been reported previously.6,8,9

Children with cerebral palsy at age 14 years were excluded. Head circumference, height, and weight were measured at ages 2, 5, 8, and 14 years by a pediatrician who was unaware of the birth weight of the child. Age was corrected for prematurity at all ages to be consistent. The relevance of correcting for prematurity diminishes with age, as the rate of growth slows, but the bias that it avoids is greatest for the most immature survivors. The mean of 3 measurements of each growth variable was recorded at each age. Children from ages 2 to 14 years were weighed wearing minimal clothing on a digital scale with an accuracy of 100 g. Height was measured according to standard guidelines,17 in either barefeet or wearing light socks, to an accuracy of 1 mm. Occipitofrontal head circumference was measured with a paper tape according to standard guidelines.17 Breast development in girls was staged according to Tanner,18 age of menarche was obtained by self-report, and testicular volume was estimated using a Prader orchidometer.19 Parents’ heights were measured, when possible, in lightly stockinged feet. Otherwise, parental heights were obtained by self-report. When data were available for both parents, z scores were averaged to obtain a midparental height z score. Otherwise, the measurement from the sole parent was assumed to represent midparental height.

z (SD) scores for the growth variables were computed relative to the British Growth Reference of 1990.20,21 A z score is calculated by subtracting the expected value for age and sex for the measurement (height, weight, or head circumference) from the child’s actual measurement and dividing the difference by the SD for the measurement. A z score of zero for height equals the median (50th centile), a z score of +2 SDs approximates the 98th centile, and a z score of −2 SDs approximates the second centile. The program could compute z scores for gestational ages as low as 23 weeks for weight and head circumference but only as low as 33 weeks for height. Growth deficiency was defined by a z score more than 2 SD below the mean (less than −2 SDs) for the growth variable.

Data were analyzed using SPSS for Windows programs.22 To compare the growth of children relative to expectations at each age, and the rate of change in z scores between consecutive ages, data were analyzed by a single group t test relative to zero for z score or change in z score. To contrast z scores and rate of change in z scores between different birth-weight subgroups, data were analyzed by linear regression with dummy variables to compare, first, NBW children with all VLBW children and, second, within the VLBW group, to compare those with a birth weight less than 1000 g with those with a birth weight of 1000 to 1499 g. Mean differences and their 95% confidence intervals (CIs) were computed either from the mean differences and their SEs or from the regression coefficients and their SEs. Dichotomous variables were compared by Fisher exact test. Differences were considered statistically significant at P<.03.

The Research and Ethics Committees of the Royal Women’s Hospital approved this study.

valid growth data at age 14 years had growth z scores at ages 2, 5, and 8 years that did not differ significantly at those ages from those with valid growth data at age 14 years who also had growth measurements at those ages (data not shown). Of children with valid growth data at age 14 years, mean birth weights and gestational ages, and the proportions who were small for gestational age (birth weight less than –2 SDs) or who developed bronchopulmonary dysplasia, differed between the 3 groups, as expected (Table 1). There were more mothers who had hypertension during pregnancy in the VLBW group, and there were no children from multiple births in the NBW group, whereas 1 in 5 VLBW children were from multiple births. There were no significant differences in race, sex, or asthma at age 14 years among the 3 groups.

Mean ages of assessment were similar in all 3 birth-weight subgroups (Table 2 and Table 3). No child exhibited precocious puberty; all were prepubertal up to age 8 years. By age 14 years, most children were advanced in pubertal development, and there were no substantial differences between birth-weight groups in the stage of puberty (Table 2).

WEIGHT

z Scores

At birth, z scores for preterm children, particularly for the ELBW subgroup, were substantially less than zero, whereas z scores for the NBW group were close to the expected values (Table 4). Both subgroups of VLBW children at ages 2, 5, and 8 years remained significantly lighter than the British Growth Reference at the same ages and were even lighter compared with NBW controls. In comparison, by age 2 years, NBW children were significantly heavier than the British Growth Reference, and they remained so to age 14 years. By age 14 years, both VLBW subgroups had mean z scores not significantly different from zero. Within the VLBW group, at each age, those with a birth weight of 1000 to 1499 g were significantly heavier than those with a birth weight less than 1000 g, except at age 14 years.
The NBW children did not change their height z scores significantly from zero between any consecutive age. Both groups of VLBW children had significant increases in height z scores between ages 2 and 5 years and between ages 8 and 14 years. Paradoxically, they had significant reductions in height z scores between ages 5 and 8 years.

**Table 1. Demographic Characteristics of Study Participants**

<table>
<thead>
<tr>
<th>Birth-Weight Subgroup, g</th>
<th>&lt;1000</th>
<th>1000-1499</th>
<th>&gt;2499</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survivors, No.</td>
<td>86</td>
<td>120</td>
<td>60</td>
</tr>
<tr>
<td>Followed up at 14 y, No. (%)</td>
<td>79 (92)*</td>
<td>100 (83)*</td>
<td>42 (70)</td>
</tr>
<tr>
<td>Cerebral palsy at age 14 y, No.</td>
<td>5</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Free of cerebral palsy and have growth data at age 14 y, No.</td>
<td>73</td>
<td>92</td>
<td>41</td>
</tr>
<tr>
<td>Maternal hypertension, No. (%)</td>
<td>17 (23)</td>
<td>18 (20)</td>
<td>1 (2)</td>
</tr>
<tr>
<td>Mother white, No. (%)</td>
<td>71 (97)</td>
<td>89 (97)</td>
<td>39 (95)</td>
</tr>
<tr>
<td>Birth weight, mean (SD), g</td>
<td>856 (102)</td>
<td>1248 (142)</td>
<td>3417 (432)</td>
</tr>
<tr>
<td>Gestational age, mean (SD), wk</td>
<td>27.5 (2.3)</td>
<td>23.6 (1.6)</td>
<td>39.9 (1.0)</td>
</tr>
<tr>
<td>Birth weight less than -2 SDs, No. (%)</td>
<td>14 (19)</td>
<td>7 (8)</td>
<td>0</td>
</tr>
<tr>
<td>Multiple births, No. (%)</td>
<td>15 (20)</td>
<td>21 (23)</td>
<td>0</td>
</tr>
<tr>
<td>Girls, No. (%)</td>
<td>39 (53)</td>
<td>42 (46)</td>
<td>16 (39)</td>
</tr>
<tr>
<td>Bronchopulmonary dysplasia, No. (%)</td>
<td>32 (44)</td>
<td>8 (9)</td>
<td>0</td>
</tr>
<tr>
<td>Asthma at age 14 y, No. (%)</td>
<td>11 (15)</td>
<td>19 (21)</td>
<td>9 (22)</td>
</tr>
</tbody>
</table>

* One child in each group was seen at age 14 years but did not have all growth measurements.

**Increments**

Peak incremental change in weight z score occurred between birth and age 2 years for the NBW group, but this did not occur in either VLBW subgroup. Children with a birth weight less than 1000 g had significant increases in z scores between ages 2 and 5 years and between ages 8 and 14 years. Children with a birth weight of 1000 to 1499 g had a significant increase in z scores between ages 8 and 14 years only (Table 4).

**HEIGHT**

**z Scores**

There were not enough length z scores at birth in the VLBW groups to make statistical comparisons worthwhile. The NBW children had height z scores that were greater than zero at all ages but were statistically nonsignificant (Table 5). Both groups of VLBW children had height z scores significantly less than zero at ages 2, 5, and 8 years, but only the ELBW subgroup had height z scores significantly less than zero at age 14 years. The NBW children were significantly taller than the VLBW children at all ages. Within the VLBW group, after age 2 years there were no statistically significant differences in height between those with a birth weight less than 1000 g and those with a birth weight of 1000 to 1499 g.

**Increments**

The NBW children did not change their height z scores significantly from zero between any consecutive age. Both groups of VLBW children had significant increases in height z scores between ages 2 and 5 years and between ages 8 and 14 years. Paradoxically, they had significant reductions in height z scores between ages 5 and 8 years.

**Table 2. Pubertal Data at Age 14 Years**

<table>
<thead>
<tr>
<th>Birth-Weight Subgroup, g</th>
<th>&lt;1000</th>
<th>1000-1499</th>
<th>&gt;2499</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free of cerebral palsy and have growth data at age 14 y, No.</td>
<td>73</td>
<td>92</td>
<td>41</td>
</tr>
<tr>
<td>Corrected age at follow-up, mean (SD), y</td>
<td>14.1 (0.2)</td>
<td>14.2 (0.3)</td>
<td>14.2 (0.2)</td>
</tr>
<tr>
<td>Girls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No menarche, No. (%)</td>
<td>6/39 (15)</td>
<td>0/42</td>
<td>1/16 (6)</td>
</tr>
<tr>
<td>Breast stage &gt;3, No. (%)</td>
<td>29/39 (74)</td>
<td>29/42 (69)</td>
<td>12/16 (75)</td>
</tr>
<tr>
<td>Boys</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left testicular volume, mean (SD), mL</td>
<td>18.4 (6.6)</td>
<td>19.4 (5.9)</td>
<td>19.6 (6.3)</td>
</tr>
<tr>
<td>Right testicular volume, mean (SD), mL</td>
<td>19.2 (6.2)</td>
<td>19.2 (5.9)</td>
<td>20.2 (6.2)</td>
</tr>
<tr>
<td>Testicular volume ≥12 mL, No. (%)</td>
<td>30/34 (88)</td>
<td>44/50 (88)</td>
<td>22/25 (88)</td>
</tr>
</tbody>
</table>

*Data are given as mean (SD), except as otherwise noted.

**Parental Height z Scores**

Height z scores were obtained for both parents for 90% (185/206) of the children, and for 9% (19/206) one parental height was obtained. The only 2 children for whom no parental height was obtained were both NBW controls. In total, 115 mothers and 42 fathers were measured. When data were also obtained for estimated heights, the mean difference between estimated and measured height was not significantly different from zero (mean, 0.5 cm; 95% CI, –0.2 to 1.2 cm). The computed midparental
The head circumference z score for NBW children was not significantly different from zero (mean, −0.20 SD; 95% CI, −0.50 to 0.10 SD), but it was for both groups of VLBW children (birth weight <1000 g: mean, −0.47 SD; 95% CI, −0.66 to −0.27 SD; and birth weight 1000-1499 g: mean, −0.38 SD; 95% CI, −0.57 to −0.20 SD). There were no significant differences between birth-weight subgroups in midparental height z scores. The NBW children significantly exceeded their midparental height z score at age 2 years (mean difference, 0.29; 95% CI, 0.02-0.57), and the difference progressively increased to age 14 years (mean difference, 0.46; 95% CI, 0.12-0.79). Within the VLBW cohorts, at age 2 years, children with a birth weight of 1000 to 1499 g had significantly lower height z scores than their parents (mean difference, −0.21; 95% CI, −0.40 to −0.01). By ages 5 and 8 years they were not significantly different from their parents, and by age 14 years they had significantly exceeded their parents’ height z score (mean difference, 0.14; 95% CI, 0.04-0.24). Children in early childhood with an ELBW had significantly lower height z scores than their parents (at age 2 years: mean difference, −0.51; 95% CI, −0.77 to −0.26; at age 8 years: mean difference, −0.31; 95% CI, −0.56 to −0.06), but by age 14 years this difference had disappeared.

HEAD CIRCUMFERENCE z Scores

There were not enough measurements at birth in the NBW controls. Both VLBW groups had substantially smaller head circumferences at birth than expected (Table 6). After birth, all 3 groups had head circumference z scores smaller than expected according to the British Growth Reference at all ages, except for the NBW children at age 14 years. The NBW children had significantly higher head circumference z scores than the VLBW children at all ages at which a comparison was possible. Within the VLBW cohorts, at all ages, children with a birth weight of 1000 to 1499 g had significantly larger head circumference z scores than those with a birth weight less than 1000 g.
Head circumference \( z \) scores in the NBW group decreased significantly between ages 2 and 5 years, and then rose significantly between ages 5 and 8 years and between ages 8 and 14 years. Both of the VLBW subgroups had significant reductions in \( z \) scores between ages 2 and 5 years and between ages 5 and 8 years and then had a significant increase between ages 8 and 14 years (Table 6). Overall, the increase in head circumference \( z \) scores between ages 8 and 14 years was larger in girls (mean, –2.55, and –2.25). Before starting growth hormone therapy at age 8 years, their height \( z \) scores were –3.40, –2.75, and –2.00. At age 14 years, after growth hormone therapy for 1 to 2 years, their height \( z \) scores were –1.25, and –1.00 (mean, 0.36, 0.15, and 0.28 SD, respectively (gain in SD: mean, 0.31; 95% CI, 0.19-0.41). Excluding the 3 children with growth hormone therapy and the 7 nonwhite children had little effect on statistical comparisons for continuous data between groups. The only exception was that the difference in weight SD score at age 5 years between NBW and all VLBW children became nonsignificant.

### Table 6. Head Circumference \( z \) Scores at Each Age

<table>
<thead>
<tr>
<th>Age, y</th>
<th>Birth-Weight Subgroup, g†</th>
<th>(&lt;1000)</th>
<th>1000-1499</th>
<th>(&gt;2499)</th>
<th>Among All Groups</th>
<th>(&gt;2499) g vs All (&lt;1500) g</th>
<th>1000-1499 g vs (&lt;1000) g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth</td>
<td>–1.42 (1.96)‡ 0.74 (0.88)‡ §</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
</tr>
<tr>
<td>2</td>
<td>–1.40 (1.04)‡ 0.62 (1.13)‡ 0.45 (0.95)‡</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
</tr>
<tr>
<td>5</td>
<td>–2.27 (0.57)‡ 0.34 (0.54)‡ 0.26 (0.56)‡</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
</tr>
<tr>
<td>8</td>
<td>–1.75 (1.06)‡ 0.10 (1.21)‡ 0.44 (1.11)‡</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
</tr>
<tr>
<td>5-8</td>
<td>–0.18 (0.52)‡ 0.09 (0.41)‡ 0.20 (0.53)‡</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
</tr>
<tr>
<td>14</td>
<td>–1.07 (1.06)‡ 0.47 (1.26)‡ 0.08 (1.14)‡</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
</tr>
<tr>
<td>8-14</td>
<td>0.77 (0.67)‡ 0.55 (0.72)‡ 0.54 (0.64)‡</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
<td>§</td>
</tr>
</tbody>
</table>

*CI indicates confidence interval; ‡, difference between ages.
†Data are given as mean (SD).
‡Statistically significant difference from zero.
§Insufficient data.

**Increments**

Head circumference \( z \) scores in the NBW group decreased significantly between ages 2 and 5 years, and then rose significantly between ages 5 and 8 years and between ages 8 and 14 years. Both of the VLBW subgroups had significant reductions in \( z \) scores between ages 2 and 5 years and between ages 5 and 8 years and then had a significant increase between ages 8 and 14 years (Table 6). Overall, the increase in head circumference \( z \) scores between ages 8 and 14 years was larger in girls (mean, –2.55, and –2.25). Before starting growth hormone therapy at age 8 years, their height \( z \) scores were –3.40, –2.75, and –2.00. At age 14 years, after growth hormone therapy for 1 to 2 years, their height \( z \) scores were –1.25, and –1.00 (mean, 0.36, 0.15, and 0.28 SD, respectively (gain in SD: mean, 0.31; 95% CI, 0.19-0.41). Excluding the 3 children with growth hormone therapy and the 7 nonwhite children had little effect on statistical comparisons for continuous data between groups. The only exception was that the difference in weight SD score at age 5 years between NBW and all VLBW children became nonsignificant.

**GROWTH DEFICIENCY AT EACH AGE**

No NBW child had a weight or height less than –2 SD at any age except one (2%) with a height less than –2 SD at age 14 years only. Compared with NBW controls, significantly more VLBW children overall had weights less than –2 SD at birth (13%, n = 22) and ages 2 (15%, n = 24), 5 (13%, n = 21), and 8 (14%, n = 22) years and heights less than –2 SD at ages 2 (11%, n = 17) and 8 (10%, n = 16) years. There were no significant differences in proportions with weights (VLBW group, 3% [n = 5]; NBW group, 0%) or heights (VLBW group, 4% [n = 7]; NBW group, 2% [n = 1]) less than –2 SD at age 14 years.

Three VLBW children had been investigated earlier in childhood for short stature and started treatment with synthetic growth hormone. As outlined in an earlier publication, none of the 3 children had growth hormone deficiency. At age 8 years, their height \( z \) scores were –3.58, –2.53, and –2.25. Before starting growth hormone therapy at age 12 to 13 years, their height \( z \) scores were –3.16, –2.40, and –2.75, respectively. At age 14 years, after growth hormone therapy for 1 to 2 years, their height \( z \) scores were –2.80, –2.14, and –2.47, respectively, with gains of 0.36, 0.15, and 0.28 SD, respectively (gain in SD: mean, 0.31; 95% CI, 0.19-0.41). Excluding the 3 children with growth hormone therapy and the 7 nonwhite children had little effect on statistical comparisons for continuous data between groups. The only exception was that the difference in weight SD score at age 5 years between NBW and all VLBW children became nonsignificant.

**COMMENT**

The VLBW children had lower mean birth weight \( z \) scores in this study relative to preterm children in the British reference data because our data pertain to survivors only and not to all births. At extreme prematurity, at any given birth weight, babies who are more mature are more likely to survive. If a cohort is then selected by birth weight, the birth-weight \( z \) score of survivors is therefore more likely to be lower than expected.

We computed sex- and age-specific \( z \) scores to facilitate statistical comparisons within groups, between groups, and across time intervals. \( z \) Scores are preferable for statistical comparisons in growth variables because parametric statistics (eg, \( t \) tests) are more widely understood and there are fewer violations of the underlying assumptions than would occur if centiles were compared by parametric statistics. Not only is it easier to quantify a change in growth with \( z \) scores than with centiles, but the interval between \( z \) scores can be converted more readily back to the basic unit of measurement, eg, grams or centimeters. Because growth varies so widely with differences in sex, and even small differences in age at measurement, and because it is desirable to compare growth between groups with variations in sex and age, it is not sensible to compare data in the basic units of measurement of the growth variable.

The \( z \) scores in our study were computed relative to the British Growth Reference of 1990. This growth reference relates to measurements made between 1978 and 1990 and included ages from 23 weeks’ gestation to 23 years. The reference data for weight and height were obtained from 7 different sources and excluded nonwhite children. In our study, the NBW children exceeded the children in the British Growth Reference data in weight by age 2 years, and...
this difference persisted to age 14 years. This raises the question of whether the British Growth Reference is appropriate as a comparison for our Australian children and highlights why it is important to have contemporaneous NBW controls from within the same population to compare with VLBW children. There are no similar growth standards suitable for Australian children. It is possible, however, that our NBW children are not representative of Australian children despite being randomly selected. We could have used the American National Center for Health Statistics data as the basis for comparison, but our conclusions regarding changes between groups and over time would not have differed.

The NBW children in our study had significant increases in weight \( z \) scores earlier than the VLBW children, between birth and age 2 years. Among the VLBW children, weight \( z \) scores accelerated between ages 8 and 14 years, suggesting there is later catch-up growth. Without a NBW comparison group and simply using the British Growth Reference data, it might have been thought that by age 14 years the VLBW children had achieved a satisfactory weight. However, they were still significantly lighter than our NBW group. The mean difference in weight \( z \) score at age 14 years between NBW and all VLBW children was 0.73 SD, representing approximately 6.3 kg for girls and 7.3 kg for boys.

By age 14 years, children with a birth weight less than 1000 g had obtained their midparental height \( z \) score and those with a birth weight of 1000 to 1499 g had exceeded their midparental height \( z \) score. As a group, however, the VLBW children were still significantly shorter than the NBW group. The mean difference in height \( z \) score between NBW and VLBW children was 0.53 SD, representing approximately 3.5 cm for a girl and 4.4 cm for a boy at age 14 years.

The midparental height \( z \) scores for both VLBW cohorts were significantly lower than zero, whereas the midparental height \( z \) score for the NBW cohort was not. Because the VLBW cohort was selected by birth weight and not by gestational age, and because smaller parents, particularly mothers, would have smaller babies at each week of gestation, it is not surprising that the midparental height \( z \) score for the VLBW cohorts was significantly lower than zero. With the secular trend toward taller adults with each subsequent generation, and because of the observed later catch-up growth of the VLBW children, it is possible that the VLBW children will exceed their midparental height as adults.

In a previous study of the shortest VLBW children, Doyle et al reported that there was approximately a 15-month delay in bone age at 8 to 12 years old, which would suggest that these short children would catch up later in childhood. Treatment with synthetic growth hormone of 3 children produced small but statistically significant gains in height SD scores. Doyle et al previously reported that these 3 children had substantially delayed bone ages and that their height SD scores for bone age were not very low. Because we did not repeat bone age measurements at age 14 years, we do not know if their bone maturation has been accelerated along with their height SD score. Consequently, the effects of synthetic growth hormone use on their ultimate adult height are uncertain.

At age 14 years, head sizes of VLBW children remained smaller (mean difference, 0.92 SD) than those of the NBW comparison group. The difference was greater in the ELBW subgroup. One SD difference approximates to 1.3 cm for girls and 1.7 cm for boys at age 14 years. The difference in head circumference might have clinical relevance because head circumference is positively associated with IQ.

The rate of change in head circumference \( z \) scores over time was unusual. In particular, in all groups there were significant increases in head circumference \( z \) scores between ages 8 and 14 years, and the increases were greater in girls. The reference data for the British Growth Reference between these ages were derived from a longitudinal study of 60 girls and 83 boys born in Edinburgh, Scotland, between 1971 and 1976. The increase in the absolute head circumference between ages 8 and 14 years averaged less than 2 cm in both boys and girls in the Edinburgh study, whereas the absolute increase in all groups in our study exceeded 2 cm (Table 3). There were no data on pubertal development in the Edinburgh study. In our study, because the increase in \( z \) scores was greater in girls and because the girls were relatively advanced in puberty, it is possible that the difference in head circumference \( z \) scores between the 2 studies is related to differences in pubertal development.

There were significantly more VLBW children than NBW controls with weights and heights less than –2 SD earlier in childhood, but the proportions diminished with age and were not significantly higher by age 14 years.

There are few other studies of growth in adolescence for complete cohorts of ELBW or VLBW children born in the era of assisted ventilation. Saigal et al reported, in abstract form, the growth at ages 12 to 16 years of 154 (91%) of 169 children with a birth weight less than 1001 g born in the central-west region of Ontario, Canada. Their results were compared with those from 125 term controls. They did not report growth \( z \) scores, but growth deficiency (measurement less than the third centile) was more frequent in ELBW children vs controls: weight, 11% vs 1%; height, 8% vs 1%; and head circumference, 16% vs 2%, respectively. These results are similar to the rates of growth deficiency in our study.

Hirata and Bosque described the outcome at ages 12 to 18 years of a cohort with a birth weight less than 1001 g cared for in one hospital during 10 years beginning in 1972. Of the original follow-up cohort of 103 children, growth data in adolescence were reported only for 32 (31%). The relevance of the data in the few children measured at ages 12 to 18 years to the original cohort was extrapolated by comparing growth earlier in childhood, but the low follow-up rate reduces the value of any results obtained. Data were reported in the units of measurement, rather than as \( z \) scores or centiles, and because the age range is so wide (6 years) at a time when growth changes so rapidly, and sex differences in growth have not been allowed for, it is not possible to compare their results directly with those from our study.

Powlis et al from England reported the growth outcome for a hospital-based cohort of 137 children with a birth weight less than 1501 g born in the early 1980s. The children were free of major neurodevelopmental
handicap and were assessed at ages 11 to 13 years, and most were only in early puberty (menarche in 22% of girls and median testicular volume of 5 mL in boys). The follow-up rate from the original number of survivors was not reported. They also assessed NBW classroom peers. Children with a birth weight less than 1501 g were significantly lighter than NBW children in their study, but the mean difference in weight was only 2.5 kg (95% CI, 0.3-4.5 kg) between the groups, much lower than that in our study. Part of the difference between the studies could be explained by the more advanced pubertal development of the children in our study, as weight increases rapidly in puberty. Powls et al14 did not report weight data for ELBW children separately. In our study, ELBW children were significantly lighter throughout childhood than those with a birth weight of 1000 to 1499 g, but by age 14 years the difference became nonsignificant. In the study by Powls et al,14 children with a birth weight less than 1501 g were significantly shorter than NBW children. The size of the mean difference in height in their study was 4.1 cm overall, similar to the size of the mean difference in height for NBW children less than 1501 g were significantly shorter than those with a birth weight of 1000 to 1499 g only at age 2 years in our study.

Powls et al14 estimated ultimate adult height from knowledge of height, sex, and bone age when their cohort was assessed. They predicted that more children would have heights less than the third centile than expected, largely because bone ages were advanced compared with chronological age. In a previous study, Doyle et al23 reported that the slowest growing children with a birth weight less than 1500 g had delayed bone ages between 8 and 12 years old. In 12 (75%) of 16 children, adult height was estimated to be less than the third centile. However, the knowledge that their height z scores for bone age were not significantly lower than their midparental height z score would suggest that they might achieve higher height z scores in adulthood. In the study by Hirata and Bosque,13 15 girls at mean age 15.6 years and 13 boys at mean age 15.5 years had similar heights (mean, 160 cm) to their mothers (mean, 161 cm), suggesting that their adult height would not be lower than that of their mothers. Because no one has reported adult height from complete cohorts of ELBW or VLBW children born in the era of assisted ventilation, it remains to be seen whether adult height is affected by birth weight.

Ericson and Kallen15 were able to link birth-weight data with height data at age 19 years for singleton men entering military service in Sweden for the birth years 1973 to 1975. For VLBW infants, their height distribution was shifted to the left, with more being less than 170 cm (approximately less than −1 SD) in height than for those with a birth weight greater than 1499 g. They did not provide data separately for ELBW infants, and the data were reported only as frequency distributions, making comparison with the present study difficult. Moreover, the years of birth were 1973 to 1975 and the survival rate at that time was less than 60%, suggesting that many were not offered assisted ventilation.

In conclusion, our group of VLBW children experienced later catch-up growth to age 14 years than previously reported. They reached or exceeded their mid-parental height z score, and might exceed their genetic potential for adult height. However, they remain smaller than their NBW peers in adolescence. Children with a birth weight less than 1000 g mostly caught up to their larger peers with birth weights of 1000 to 1499 g by age 14 years. Because growth continues beyond age 14 years, these children should be measured again in adulthood.

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