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## COMPLETION OF GROWTH IN THE LOWER LIMBS IN RELATION TO BIOLOGICAL DEVELOPMENT MENARCHE, AND INHERITED FACTORS

*By*

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The literature contains numerous reports on the relation between signs of puberty, inherited factors, relative height during the growing period, and the time of declining growth and cessation of increment in total height in children.

On the other hand, there seem to be sparse and divergent data on the time when longitudinal growth in the lower limbs terminates and the relation between this time, puberty, inherited factors, and relative height during the growing period.

A definite prediction of the time at which the growth of the lower limbs may be expected to cease may be of considerable clinical interest, especially in the treatment of anisomelia<sup>1</sup> by epiphysiodesis.

*Wilson & Thompson* (1939) found agreement between the length of the lower limbs in mothers and their daughters as well as between fathers and their sons. On this basis they worked out a method for predicting the expected correction obtainable by epiphysiodesis.

*Gill & Abott* (1942), on the other hand, found prediction of final height on the basis of parent height to be inaccurate. They felt that a more accurate prediction could be obtained on the basis of relative height during the growing period. Compared with children of the same age, there was agreement between the relative height during the growing period and after growth had ceased.

*Anderson & Green* (1948) were unable to confirm *Gill & Abott's* observations. In their experience, there would be a comparatively early

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<sup>1</sup> anisomelia = unequal leg length.

cessation of growth in children who had relatively long lower limbs before the age of 14; reversely, growth ceased comparatively later in children whose lower limbs were relatively short during the growing period.

The relationship between the growth of the spine and of the lower limbs has been studied by *Goff* (1960). He states that as a rule growth ceases 6–12 months earlier in the lower limbs than in the spine. Investigating 200 normal children *Tupman* (1962) found that the growth of the lower limbs occurred at a steady rate, while in the spine the growth rate varied, usually with a prepuberal spurt. Growth of the spine continued for a considerably longer period than lower-limb growth.

*Gill & Abbott* (1942) described a method for predicting growth arrest by epiphysiodesis, based on the observation that growth terminated at 18½ years of age in boys and at 16½ years in girls. Age was calculated as skeletal age on the basis of the development of the hand bones.

*White & Stubbins* (1944) reported that lower-limb growth ceased at 16 years of age in girls and at 17 in boys.

According to *Green & Anderson* (1947) the time at which growth in the lower limbs terminated might vary by 4–5 years by chronological age, but considerably less in relation to skeletal age. In boys lower-limb growth ceased between a skeletal age of 15–17 and in girls between a skeletal age of 13–15. The increment during the last skeletal year was very slight, and for practical reasons the average time of cessation of growth was estimated as 16/3<sup>1</sup> in boys and 14/3 in girls. Radiological closure of the epiphysial zones occurred at the same age or at maximum intervals of a few months.

*Goff* (1960) found the increment in total height to cease at an average skeletal age of 17/9 (standard deviation 9.96 months) in boys and at 16/2 (standard deviation 13.6 months) in girls.

*Tupman* (1962) found longitudinal growth in boys to cease at an average skeletal age of 15/4 in the femur and of 15/5 in the tibia; in girls at an average skeletal age of 14/2 in the femur and of 13/7 in the tibia.

These previous reports on the average time at which growth in the lower limbs ceases are tabulated below (Table 1), corrected on the basis of the information given by the various authors in respect to a comparable tabulation of the results.

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<sup>1</sup> The figure after the stroke indicates months.

TABLE 1  
*Age at which Growth in the Lower Limbs Terminates.*

| Author                            | Skeletal age |       | Chronological age |        |
|-----------------------------------|--------------|-------|-------------------|--------|
|                                   | Boys         | Girls | Boys              | Girls  |
| <i>Gill &amp; Abott</i> .....     |              |       | 18/6              | 16/3   |
| <i>White &amp; Stubbins</i> ..... |              |       | ca. 17            | ca. 16 |
| <i>Green &amp; Anderson</i> ..... | 17/3         | 15/3  |                   |        |
| <i>Goff</i> .....                 | 17/0         | 15/5  |                   |        |
| <i>Tupman</i> .....               | 15/5         | 13/11 |                   |        |
| <i>Present study</i> .....        | 15/0         | 13/6  | 15/8              | 13/11  |

Thus, the results found in the American series of *Gill & Abott*, *Green & Anderson*, and of *Goff* are at variance with *Tupman's* British series.

Moreover, there are divergences in the evaluation as to whether the prediction of the time at which lower-limb growth ceases is more accurate on the basis of parent height or of relative height during the growing period.

Lastly, the relationship between the time of menarche and cessation of growth in the lower limbs does not appear to have been studied.

A further analysis of these factors would, therefore, seem of interest.

#### MATERIAL

The material—derived from the Orthopaedic Hospital, Copenhagen, Departments 1, 2, and 3—comprises 108 patients, 46 boys and 62 girls, on whom regular spot-orthoradiographic measurements of the lower limbs were done at least twice before and at least once after the cessation of growth.

In all cases the radiography was done to measure accurately an existing anisomelia which was caused in 66 cases by the sequelae of poliomyelitis, in 8 cases by epiphysial injury, in 3 cases by fracture, in 5 cases by other factors, while in the last 26 it was congenital. Epiphysiodesis was performed before cessation of growth in 99 patients.

#### METHODS

The time of cessation of growth was determined on the basis of curves representing the length of the femur and tibia as a function of age (cf. Fig. 1). It was not possible in any case to demonstrate a de-

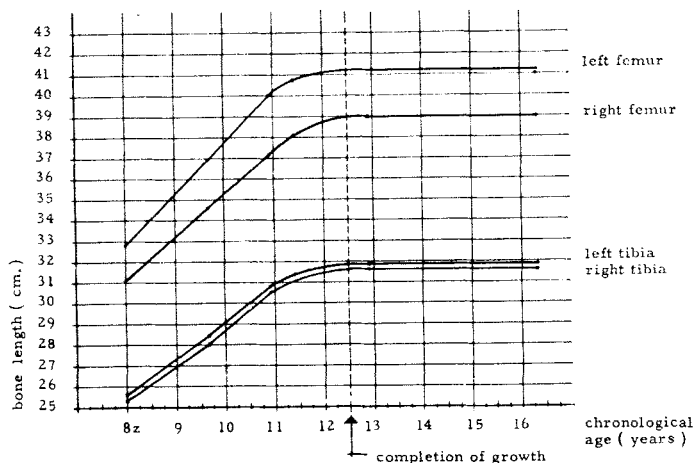


Fig. 1.

Example of growth curves for the femora and tibiae.

finite difference between the time of cessation of growth in the femur and in the tibia.

In all cases where the course of the curve after cessation of growth was based on only one measurement, the epiphysial lines had closed at the time of this measurement.

The material includes only cases submitted to a sufficient number of measurements at suitable intervals around the time when growth ceased, so that this time could be determined with an accuracy of about 3 months.

The time of cessation of growth is represented by the beginning of the horizontal part of the curve.

Determination of skeletal age was done by means of the *Greulich & Pyle* (1959) method.

Determination of skeletal age was performed before plotting the growth curves. In cases where determination of skeletal age had not been done at the time of cessation of growth, the skeletal age at this time was calculated by interpolation between the nearest determinations. In a few cases, in which the hand bones had completed their development when first investigated after cessation of growth, the skeletal age was calculated by extrapolation from the preceding determination.

Erect height without shoes was measured—in patients with anisomelia with wooden blocks under the shorter leg.

In patients with a true unilateral lengthening of a lower limb, the erect height was measured with weight-bearing on the shorter (normal) leg.

In patients who had epiphysiodesis during the growing period the erect height was corrected by adding the number of centimetres which the procedure was computed to have equalized, calculated by the prediction method of *Green & Anderson* (1947).

In 2 cases the true erect height could not be measured because of structural scoliosis.

In practically all cases one of the parents—in some cases both—were present at the examination. In that case their erect height without shoes was measured. In other cases the information regarding parent height was anamnestic. In 10 instances this information was available only for one of the parents and in 4 instances for neither because of adoption or too vague data.

The age at onset of the menarche could be stated with an accuracy of about 3 months—in relation to a particular event—in 40 girls.

Attempts at recording the age at onset of the menarche in the mothers resulted in data which were felt to be too inaccurate to afford a definite basis for comparing the age at menarche in mothers and daughters.

## RESULTS

### 1. Age at Cessation of Growth in Lower Limbs.

The results are given in Table 2 and Fig. 2.

In boys cessation of growth in the lower limbs occurred at an average chronological age of 15/8 and an average skeletal age of 15/0 years.

In girls growth ceased at an average chronological age of 13/11 years and an average skeletal age of 13/6 years.

The standard deviation ( $s_x$ ) of the results may be seen from Table 2.

It will be seen that the standard deviation ( $s_x$ ) is of the same order of magnitude in both sexes, but considerably greater when the time was calculated on the basis of chronological age than skeletal age.

TABLE 2  
*Standard Deviation ( $s_x$ ) for Time of Cessation of Growth in the Lower Limbs.*

| Sex         | Chronological age       | Skeletal age           |
|-------------|-------------------------|------------------------|
| Boys .....  | $\pm 12$ months 21 days | $\pm 7$ months 10 days |
| Girls ..... | $\pm 11$ months 15 days | $\pm 7$ months 6 days  |

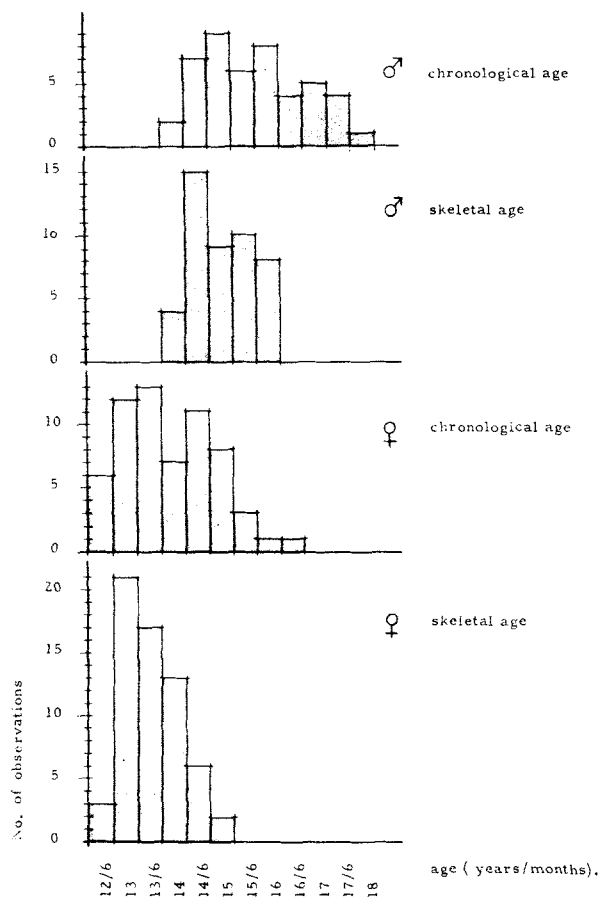


Fig. 2.  
Age at completion of lower-limb growth.

Fig. 2 shows that the greater standard deviation using chronological age is due to the fact that a number of the patients were late in completing their growth. Thus, biological development was considerably more often retarded than accelerated.

## 2. Final Length of Lower Limbs in Relation to Relative Length During the Growing Period.

In Tables 3 and 4 boys and girls respectively are divided into groups, as far as possible equally large, according to the length of the lower limbs at a skeletal age of 12/0 in the boys and 10/0 in the girls.

TABLE 3  
*Boys.*

| Lower-limb length at skeletal age 12/0 | Average skeletal age at cessation of growth | No. of observations |
|----------------------------------------|---------------------------------------------|---------------------|
| 62.5-71.9 cm.                          | 14/11 years                                 | 10                  |
| 72.3-76.4 cm.                          | 15/5 years                                  | 9                   |
| 76.8-82.6 cm.                          | 14/11 years                                 | 10                  |

TABLE 4  
*Girls.*

| Lower-limb length at skeletal age 10/0 | Average skeletal age at cessation of growth | No. of observations |
|----------------------------------------|---------------------------------------------|---------------------|
| 60.5-66.1 cm.                          | 13/3 years                                  | 10                  |
| 66.1-68.3 cm.                          | 13/7 years                                  | 10                  |
| 68.9-75.1 cm.                          | 13/8 years                                  | 10                  |

Accordingly, the maximum variations in lower-limb length at the ages concerned were 20 cm. in boys and 15 cm. in girls.

A total of 29 boys and 30 girls were followed from the named ages until cessation of growth. There does not seem to be any methodical difference in the length of the growing period in the different groups of patients. Thus, information regarding the lower-limb length about 3 years prior to the cessation of growth does not appear to afford increased security in predicting when growth will be completed.

### 3. Time of Completion of Lower-Limb Growth in Relation to Onset of Menarche.

Fig. 3 gives the computed results as to age at cessation of lower-limb growth less age at onset of menarche. Positive statements, thus, signify that the cessation of growth occurred later than the menarche and *vice versa*.

It was only in 4 cases that the difference between the age at cessation of growth and the age at menarche exceeded 15 months.

When disregarding these 4 cases, the mean value for the age at cessation of growth less the age at menarche is +4.03 months and the standard deviation ( $s_x$ ) on the observations  $\pm 5.18$  months.

Only in one patient did growth cease more than 4 months prior to

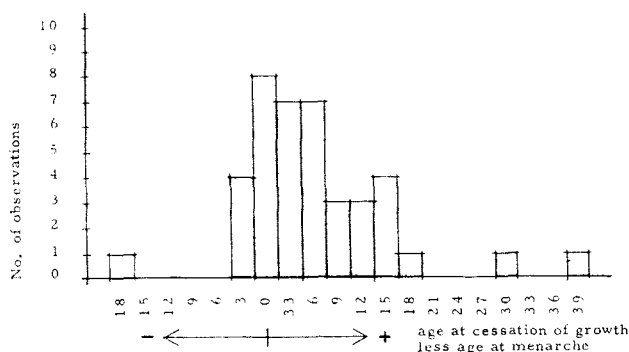


Fig. 3.

Difference between age at cessation of lower-limb growth and age at menarche.

menarche. At cessation of growth this patient was 13 months biologically retarded, and her erect height was identical with her mother's.

In 3 patients growth ceased more than 18 months after the onset of menarche—19, 31, and 40 months respectively. Only one of them was biologically retarded (14 months) at completion of growth, one was 5 months accelerated, and in one the skeletal age was identical with the chronological age.

No clinical signs of hormonal disturbances were demonstrable in these 4 patients. The one in whom growth ceased 19 months after the menarche was 15 cm. taller than her mother, the other three 0, 1, and 7 cm. taller.

The average age at menarche was  $13\frac{1}{4}$  years (standard deviation ( $s_x$ )  $\pm 12.9$  months).

The patient whose age at cessation of growth less age at menarche was calculated as -17 months did not have her menarche until  $15\frac{1}{5}$  years of age, and the patient in whom this value was +40 months had her menarche as early as  $11\frac{1}{3}$  years of age, while the patients having the values +31 and +19 had had their menarche at  $13\frac{1}{10}$  and  $13\frac{1}{5}$  years respectively. In 2 cases the difference was thus due to a marked divergence from the average age at menarche as reported anamnestically, and with the consequent inaccuracy, while in the other two it was due to a marked divergence in the objectively demonstrated difference from the average age at cessation of growth.

On this basis it is impossible to advance any definite explanation of the small number of individual, marked divergences from the average difference between age at cessation of lower-limb growth and at the onset of menarche.

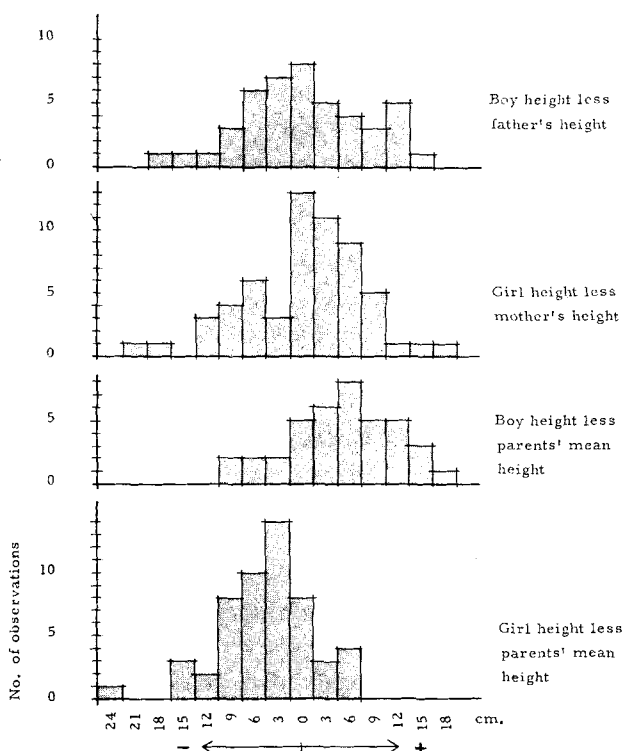


Fig. 4.

Difference between child height and parents' height.

#### 4. Final Erect Height in Relation to Parents' Height.

Fig. 4 gives the distribution of the values representing the boys' erect height less their fathers' height, the girls' height less their mothers' height, and the height of girls and boys less the mean values of both parents' height.

The boys' height was usually a little over and the girls' usually a little under the mean parent height. Within each sex there were marked variations (up to 25 cm.) between child height and parent height. Only the most marked variations can be eliminated by comparing the height with the mean value of the two parents' height.

#### DISCUSSION

The present results are based on a study of a material consisting predominantly of children suffering from more or less severe sequelae

of poliomyelitis and congenital abnormalities. However, the time of cessation of growth must be assumed to be governed by hormonal factors, and it does not appear likely that the diseases represented in the material could have influenced the hormonal factors (although it cannot be excluded). Studying 17,589 schoolgirls in Copenhagen during the period 1949–50 *Boljen, Rasch & Benzon* (1954) found the menarche to occur at the average age of 13 years 9 months, the standard deviation being  $\pm 1.0$  year. The average age at menarche found in the present series, 13 $\frac{1}{4}$  years (standard deviation 12.9 months), is in agreement with their findings. This increases the likelihood that in the hormonal respect the series is “normal”.

The average age at cessation of growth found in the present series accords better with *Tupman's* British series than with the results of the American studies which, however, show mutual divergences. This may possibly be due to a more inhomogeneous composition of the American series.

The study on the ratio of relative lower-limb length during the growing period to the final lower-limb length was based only on a small series of inhomogeneous composition, so that the results can be merely of orientating significance. Since growth in the lower limbs and in the spine does not cease at the same time, these two phenomena may be governed by different hormonal factors. Consequently, it is not possible to draw direct conclusions analogous to the ratio total height during the growing period to that after cessation of growth. Further elucidation requires a larger and more homogeneous material.

Long-lasting disease and surgical procedures may have retarded longitudinal growth in a number of the present patients. Therefore, the results of the study on the ratio child height to parent height are not comparable with corresponding studies of normal series. On the other hand, it is usually in this very type of case that epiphysiodesis is indicated. On the basis of the marked variations between child height and parent height it may, therefore, be concluded that considerable errors may be involved by a calculation of the expected correction (cf. *Wilson & Thompson*) by epiphysiodesis—on the assumption that children will attain the same height as their parent of the same sex.

#### SUMMARY

Based on repeated orthoradiographic measurements in 46 boys and 62 girls lower-limb growth was found to cease at an average chrono-

logical age of 15/8 years and an average skeletal age of 15/0 years in boys and at an average chronological age of 13/11 years and an average skeletal age of 13/6 years in girls. The standard deviation was, in both sexes, about 12 months according to chronological age and about 7 months according to skeletal age.

Information on the height, in relation to children of the same age, during the growing period does not appear to increase the accuracy in predicting the time of completion of lower-limb growth.

In 36 girls lower-limb growth ceased an average of 4 months after the menarche. Only in 4 did the difference exceed 15 months.

Analysis of the relation between total height in 104 full-grown children and their parents indicated that prediction of the correction obtainable by epiphysiodesis will be inaccurate if it is based on the ratio patient height to parent height.

#### RESUME

En se basant sur des mensurations orthoradiographiques répétées de la croissance des membres inférieurs chez 46 garçons et 62 filles, on a constaté que la croissance cesse à une moyenne d'âge chronologique de 15/8 et une moyenne d'âge squelettique de 15/0 ans chez les garçons et à une moyenne d'âge chronologique de 13/11 et une moyenne d'âge squelettique de 13/6 ans chez les filles. L'écart standard, pour les deux sexes, était d'environ 12 mois par rapport à l'âge chronologique et d'environ 7 mois pour l'âge squelettique.

Des renseignements sur la grandeur, par rapport aux enfants du même âge, pendant la période de croissance, ne semblent pas accroître la précision avec laquelle on peut prédire l'achèvement de la croissance des membres inférieurs.

Chez 36 filles, la croissance des membres inférieurs avait cessé en moyenne 4 mois après la menstruation. Chez 4 seulement, la différence a excédé 15 mois.

Une analyse entre la grandeur totale de 104 enfants ayant achevé leur croissance et celle de leurs parents indique que la prédiction de la correction qui peut être obtenue par épiphysiodèse ne sera pas exacte si elle est basée uniquement sur le rapport direct entre la grandeur du sujet et celle de ses parents.

## ZUSAMMENFASSUNG

Auf Grund von wiederholten orthoradiographischen Messungen an der unteren Extremität von 46 Knaben und 62 Mädchen wurde gefunden, dass das Wachstum in einem durchschnittlichen chronologischen Alter von 15/8 Jahren und einem durchschnittlichen Skeletalter von 15/0 Jahren bei Knaben und in einem durchschnittlichen chronologischen Alter von 13/11 Jahren und einem durchschnittlichen Skeletalter von 13/6 Jahren bei Mädchen aufhört. Die Durchschnittsabweichung war bei beiden Geschlechtern ungefähr 12 Monate hinsichtlich des chronologischen Alters und ungefähr 7 Monate hinsichtlich des Skeletalters.

Aufschluss über den Höhenwuchs während der Wachstumsperiode in bezug zu Kindern des gleichen Alters, scheint die Genauigkeit der Vorhersage über den Wachstumsabschluss der unteren Gliedmasse nicht zu vermehren.

Bei 36 Mädchen hörte das Wachstum der unteren Gliedmasse durchschnittlich 4 Monate nach der Menarche auf.

Die Analyse der Beziehung zwischen Gesamthöhe bei 104 voll erwachsenen Kindern und deren Eltern zeigte, dass die Vorausbestimmung der durch Epiphyseodesis erhaltbaren Korrektur ungenau sein wird, wenn ihr das Verhältnis der Patienten-Höhe zur Eltern-Höhe zu grunde gelegt wird.

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