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SKELETAL MATURATION IN A LONGITUDINAL STUDY OF BELGIAN BOYS

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Abstract: We made use of the Belgian Longitudinal Growth Study of the Normal Child (Graffar 1958) to produce centiles for skeletal maturation scores (TW2 method) and for bone age at each chronological age between 3 and 15 years in boys. Until 4 years of age, skeletal maturation and bone age tend to be advanced with respect to chronological age, but this trend reverses during the later prepubertal ages. At puberty, they seem to catch up again this delay. Maturation rate for the TW2 bone scores shows a regular increase from childhood till puberty. The RUS score increments show a tendency to decrease till 10 years of age, but then show a clear adolescent spurt. The maturation rate of carpal bones shows a peak around 7 to 8 years of age.

Key words: Skeletal maturation

Introduction

Maturation is a measure of the rate of development of a child. It indicates how far a child has progressed in his developmental process towards adulthood. Children with the same adult height, for example, but with varying rates of maturation, will have different heights at any particular age throughout their growth process, simply because slow maturing children take somewhat more time to complete their growth process than fast maturing children. So, one should bear in mind that, in a population, the variation in size (height for example) at a particular age is partly due to a variation in the genetic predisposition for being small or tall, but also to a variation in maturation, or tempo of growth. This relationship between growth and maturation makes that chronological age has its limits in evaluating the growth of a child.

Maturation is measured on a scale with a fixed starting and ending point, corresponding respectively, with the stages of complete immaturity and full development. Intermediate stages are observed as qualitative changes, independent of size, and occurring in an irreversible order. During childhood, the number of erupted teeth provide a good system for evaluation of the maturation of a child (Demirjian et al. 1973), while at adolescence, various characteristics of pubertal development (pubic hair, axillary hair, menarche, genital and breast development) provide a criterium to estimate maturation (Tanner 1962, Marshall et al. 1969, 1979). However, by far the most commonly used criterium is skeletal maturation, which is based on the fact that osseous development goes through a number of well-defined and easily recognisable stages, that occur in an irreversible order, and are independent of the size of the bones. The final stage in the process of skeletal maturation corresponds with complete closure of the epiphyses of the long bones, and, hence, also coincides with the end of the growth process of the long bones. Skeletal maturation is to some extent related to dental and sexual maturation (Marshall 1974). It is also applicable during fetal development (Birkbeck 1984) and in newborns (Neyzi et al. 1984).

Although various parts of the skeleton can be used to examine bone maturation, most methods are restricted to particular areas of the body, such as the knee (Roche et al. 1975b) or the hand and wrist (Todd 1931, Greulich and Pyle 1959, Tanner et al. 1962, 1975), for example. Particularly, X-rays of the hand and wrist are relatively easy to take and have shown to be very useful in the determination of skeletal maturation, since that area of the skeleton shows a relatively large number of bones, with fairly well-recognisable stages of development, or maturation indicators. The skeletal maturation of a child can be expressed in terms of a maturation score (Tanner et al. 1962, 1975), but in all instances, one can calculate a child's bone age (or skeletal age) which is the average age of children in the normal population who have the same maturation as that particular child.

Skeletal maturation or bone age are powerful tools to evaluate the normality of a child's growth, since they allow to better interpret a child's growth advancement or retardation. Indeed, it allows, for example, to estimate the amount of growth delay that is simply attributable to a lower tempo of growth and the amount of retardation, which is due to factors that may affect its growth potential. It is particularly, the latter sort of information, together with information about the height of the parents, that is important to pediatricians in order to estimate the severity of the growth delay in various growth disturbing diseases. Since skeletal maturation is related to the growth process and can express (in terms of a percentage, for example) how much of the process is completed at a certain age of the child, it also provides possibilities to make predictions of adult size (Tanner et al. 1975, Roche et al. 1974). In terms of public health, skeletal maturation can be used to reveal environmental changes.

Such as for growth, skeletal maturation reflects an interaction between genetic and environmental factors (Garn et al. 1963, 1966), stressing the need for population specific references for maturation scores. The aim of the present study is to present centiles for maturation scores and bone age in Belgian boys, based on longitudinal data (Graffar 1958), and using the TW2 (Tanner-Whitehouse 2) method (Tanner et al. 1975). Several authors have shown that the TW method (TW1) is more reliable than the Greulich–Pyle method (Roche et al. 1970; Johnson et al. 1973, Roche 1978).

Materials and Methods

The data comes from the longitudinal survey of Belgian children, previously described by Graffar (1958), Wachholder et al. (1975) and Hauspie et al. (1980). This study is known as the Belgian Growth Study of the Normal Child and was part of a series of longitudinal growth studies, conducted in different European countries and coordinated by the International Children's Centre in Paris (Falkner 1955). The actual sample is representative of the Brussels' population.

X-rays were taken at yearly intervals, within 14 days from birthdays, between 1 and 15 years of age. The material consists of 581 X-rays, taken on 50 boys. There was an average number of 11.6 radiographs per subject taken over the 14 years period. All radiographs were rated by one of the authors (G. G.) according the TW2 method (Tanner et al. 1975). The reliability of the authors' technique was tested by comparing his ratings of a set of 100 X-rays from the Harpenden Longitudinal Growth Study with ratings of the same set by an expert in the field (Beunen 1985). The overall percentage of agreement between independent ratings of the 100 radiographs was 86.4%, the great majority of the differences was limited to one stage only. Reproducibility of the author's own ratings was checked on a subset of 50 X-rays and the agreement between two ratings of these same subset was 87.2%. These values are in good agreement with those obtained by Beunen and Cameron (1980), higher than those obtained by Baughan et al. (1979), van Vanrooij-

Ysselmuiden et al. (1978), Helm (1979), and Wenzel et al. (1982). The difference in bone age between the independent ratings was only 0.045 years (S.D. = 0.416 years) and between the 1st and 2nd ratings only 0.124 years (S.D. = 0.316 years).

Results

The centile values of the maturity scores are shown in Figure 1 for the 20 bones, in Figure 2 for the RUS bones and in Figure 3 for the carpal bones. The centile lines of the respective bone ages are shown in Figures 4 to 6. The numerical data are given in Appendices 1 and 2. Figure 7 shows the differences in TW2 (20 bones), RUS and carpal bone age, between the Belgian and British population. At the earliest ages, the Belgian boys are advanced by about 0.5 years at the age of 1 year, but from 4–5 year onwards, they are slightly retarded (maximum delay at age 7). At puberty, they seem to catch up and to be in advance again from the age of 13 years onwards. RUS bones follow more or less the same trend as TW2 bone age, but with a slightly more pronounced delay in the period 4 to 12 years, and a stronger catch-up towards puberty. On the contrary, carpal bones are characterized by an advance till the age of 5 years, and a delay from age 6 years onwards, which does not seem to be catched up during adolescence.

Comparison of the TW2 bone age at each chronological age in the Belgian sample with various other populations is shown in Figure 8. It seems that Belgian boys have a lower skeletal maturity than Finnish (Tiisala et al. 1969, 1971), the Polish of good socio-economic conditions (Kopczynska-Sikorska et al. 1984), and the Australians from British ancestry (Roche et al. 1971). These patterns are different from the Greulich–Pyle bone ages observed by Roche et al. (1975a) for the U.S. population, where a constant decrease of the difference between chronological age and skeletal age was observed between 6 and 11 years of age.

Theoretically, the mean increment of bone age will be one year for each one-year increase of chronological age, but in practise, the range seems to vary between 0 and 2 years in the age range 3 to 16 years (Johnston 1964a, 1971, Marshall et al. 1969, Malina 1970, Tanner et al. 1975). As expected, children with advanced maturation in early childhood have lower rates of maturation later on; those with delayed maturation during childhood have higher rates of maturation at adolescence.

Hewitt et al. (1961) observed a pubertal spurt in the bone maturation. This acceleration and the corresponding sexual differences have been observed by Tanner et al. (1975), but with a different pattern for the RUS and carpal bones. Of course, this phase of acceleration is under the control of androgenic and oestrogenic hormones.

Comparison of maturation rates in the Belgian and British boys are shown in Figure 9 for the TW2 bones, in Figure 10 for the RUS bones, and in Figure 11 for the carpal bones. These figures show the increments of maturation scores calculated from the mean scores at successive ages. The overall pattern in maturation rate is fairly similar between the Belgian and British boys for the three types of maturation scores. However, there is a tendency towards lower maturation rate prepubertal ages and at almost all ages for the carpals. It is also note-worthy that between age 7 and 8 there is a small peak in the maturation rate of Belgian boys. One could postulate that this peak might be related to the pre-pubertal peak in height growth, but a more detailed analysis of the individual patterns of maturation rate in relation to the pattern of growth velocity can only provide more accurate information about this eventual relationship.

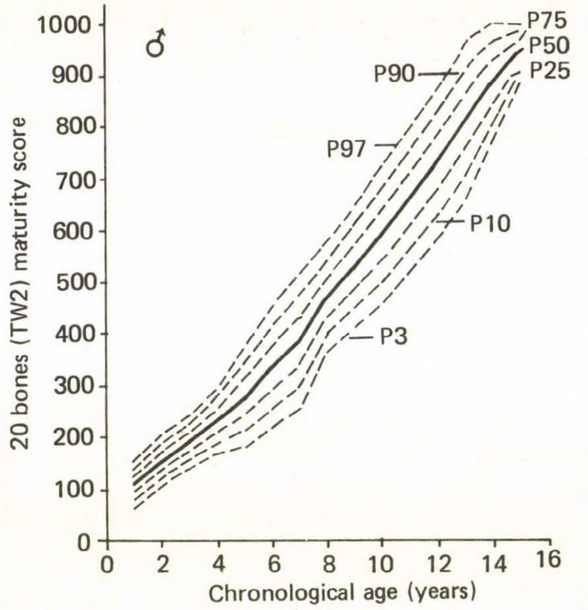

Fig. 1: Centiles of the maturity scores for the 20 TW bones in Belgian boys

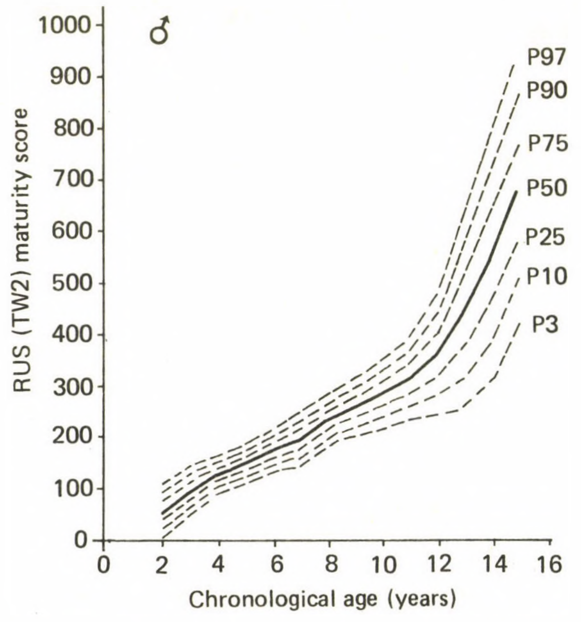

Fig. 2: Centiles of the maturity scorse for the RUS bones in Belgian boys

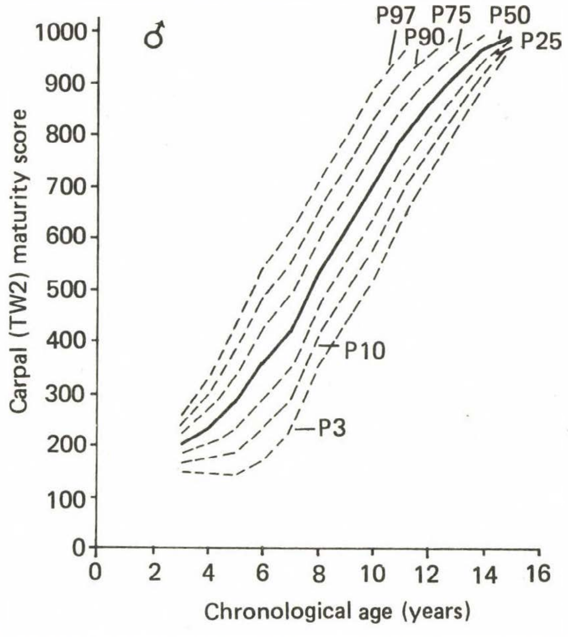

Fig. 3: Centiles of the maturity scores for the CARPAL bones in Belgian boys

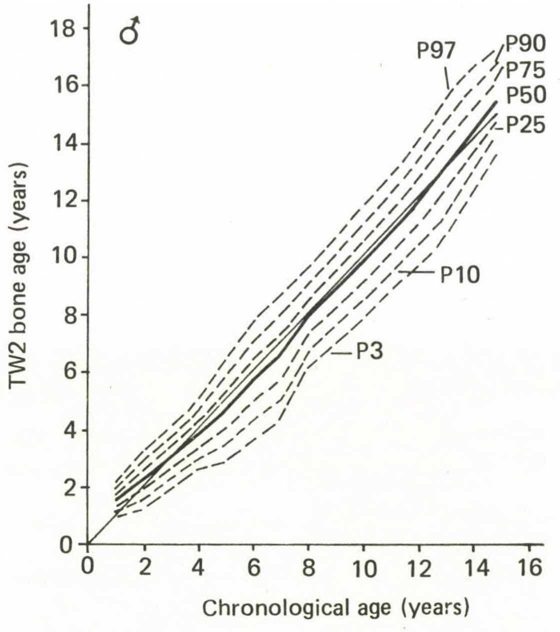

Fig. 4: Centiles of the TW2-bone age in Belgian boys

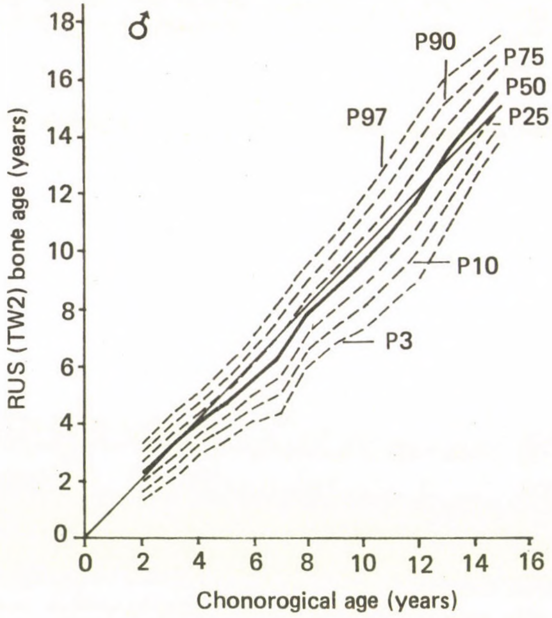

Fig. 5: Centiles of the RUS-bone age in Belgian boys

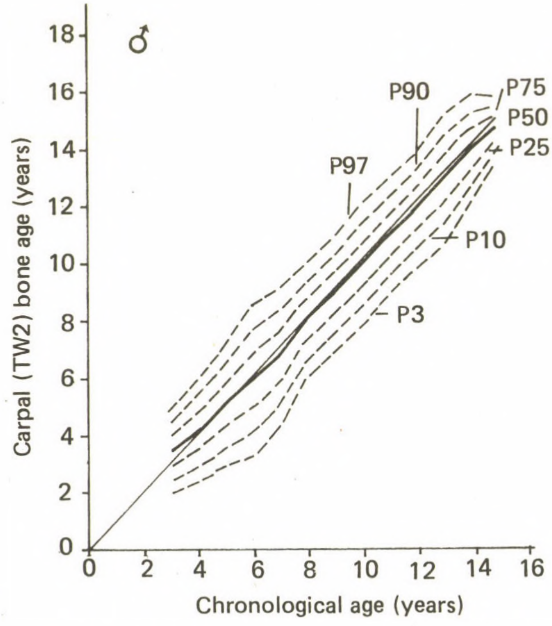

Fig. 6: Centiles of the CARPAL-bone age in Belgian boys

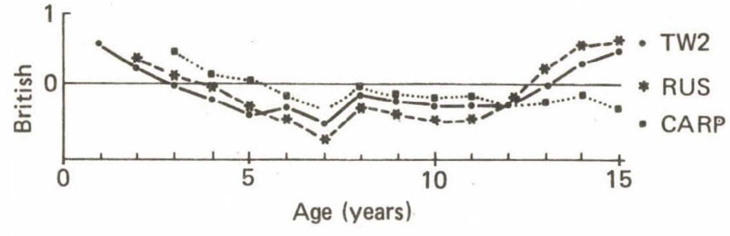

Fig. 7: Differences in TW2, RUS and CARPAL bone ages between Belgian and British boys

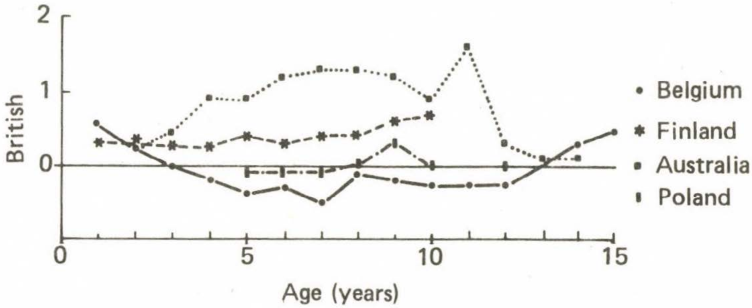

Fig. 8: Comparison of the TW2 bone age in Belgian boys with various other populations

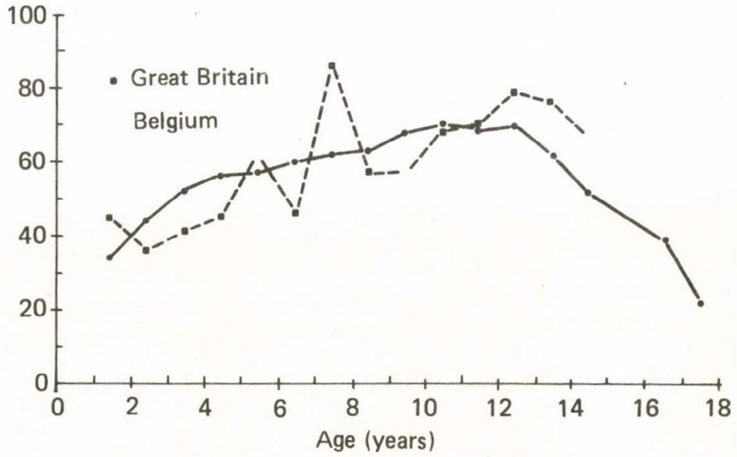

Fig. 9: Comparison of maturation rates in the Belgian and British boys for the TW2 bones

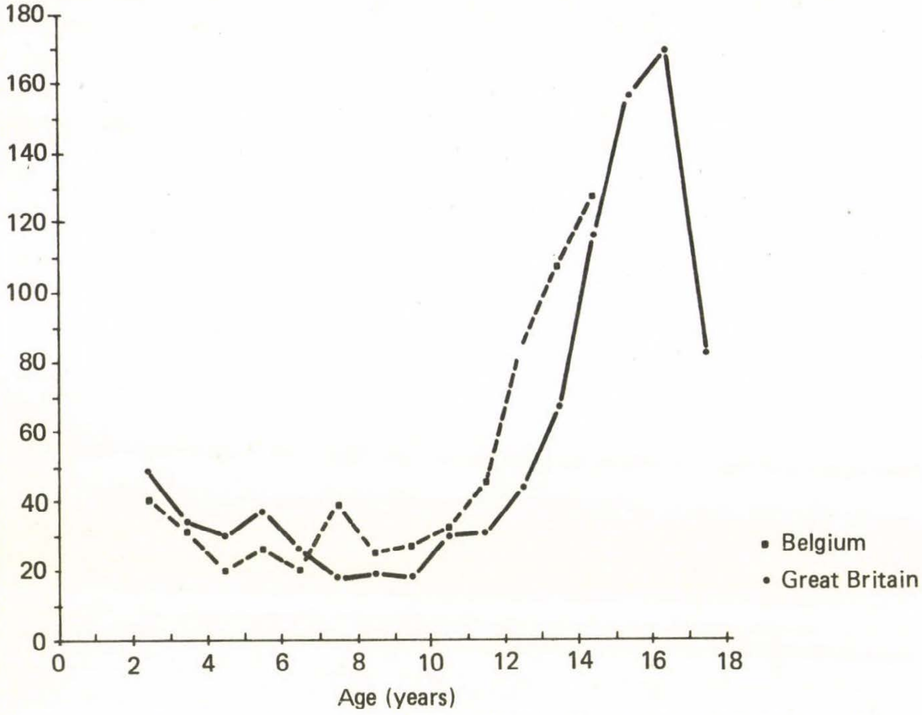

Fig. 10: Comparison of maturation rates in the Belgian and British boys for the RUS bones

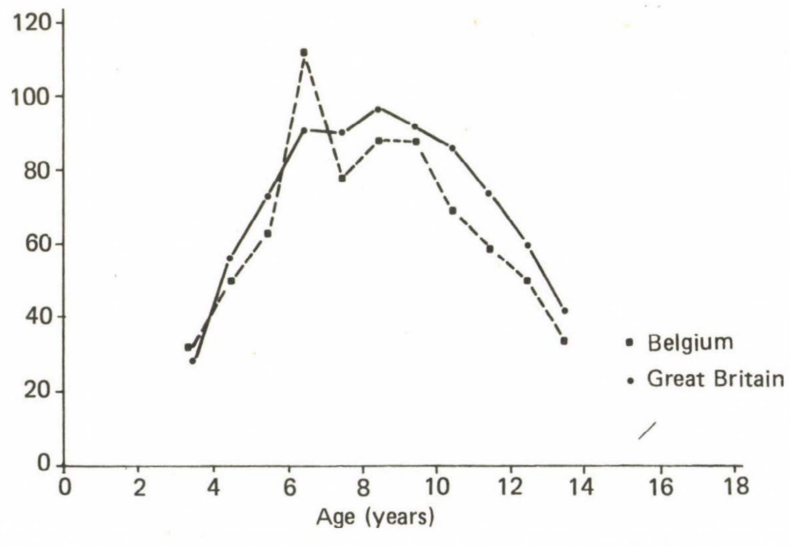

Fig. 11: Comparison of maturation rates in the Belgian and British boys for the CARPAL bones

Discussion

Comparison of different populations is difficult because of the variation in genetic and environmental factors. Socio-economic differences in skeletal maturation have been observed within the same population by De Wijn (1053), Greulich et al. (1953), Chang et al. (1963), Low et al. (1964), Kopczynska-Sikorska (1964), Andersen (1968), Rea (1971), Garn et al. (1973), and Kristmundottir et al. (1984a). However, it appears that socio-economic conditions have less effect on skeletal maturation than on growth in height or other somatic traits (Kopczynska-Sikorska et al. 1984). This might explain why in some populations only slight or no social differences were observed (Asiel 1966, Sempé 1968, Graffar 1971, Descamps et al. 1974, Roche et al. 1975a, 1978).

Low nutritional status is related to a retardation of skeletal maturation (Blanco et al. 1972). In early infancy, children do not show a clear retardation, but at the time of weaning or in conditions of undernutrition, children tend to delay in skeletal maturation (Massé et al. 1963, Bala 1974). Effects of undernutrition have been observed also by Abbott el al. (1950), Snodgrasse et al. (1955), Dreizen et al. (1958), Spies et al. (1959), Acheson et al. (1962), Malcolm (1970), Frisancho et al. (1970), and Garn et al. (1975). Boys are more sensible towards adverse nutritional conditions than girls (Abbott et al. 1950, Widdowson et al. 1954). Moreover, skeletal maturation in boys is more sensitive to other environmental factors than in girls (Acheson et al. 1954, Falkner 1958). This phenomenon can explain why bone age in boys, sometimes, shows a greater dispersion than in girls (Tiisala et al. 1968).

On the other hand, chronic protein-energy malnutrition has a relatively greater effect on growth than on skeletal maturation (Frisancho et al. 1970, Lampl et al. 1978, Martorell et al. 1979, Johnston et al. 1984). It has also been observed that supplementary protein intake results in an acceleration of maturation (McNair et al. 1938, Dreizen et al. 1954, Lampl et al. 1978, Martorell et al. 1979). In general, overnutrition and obesity is associated with an accelerated skeletal maturation (Bruch 1939, Garn et al. 1959, 1960, Frisk et al. 1966, Maresh 1966).

Skeletal maturation is positively correlated with weight, subcutaneous fat thickness, but the association with these growth variables is rather low (Simmons et al. 1943, Garn et al. 1961, Johnston 1964b, Maresh 1966). It is also positively correlated with height growth (Tiisala et al. 1969, 1971, Mazess et al. 1971), and with percentage attainment of adult stature (Bayley et al. 1952) and with maturation of sexual characteristics (Simmons et al. 1943).

Factors such as frequency of diseases (Douglas et al. 1958) also influence skeletal maturation. Chronic diseases are related to a delayed maturation (Hewitt et al. 1955, Falkner 1958, Tiisala et al. 1966, Hauspie et al. 1977, Kristmundottir et al. 1964b).

It is difficult to talk in terms of „racial" differences in skeletal maturation, since we are then considering groups that differ in so many factors: socio-economic status, nutrition, hygienic situation, climate, physical activity, etc. At least from family studies, it has been shown that there is genetic involvement in the order of appearance and ossification of the different bone centers (Garn et al. 1962). All together, there are many reports in the literature on so-called racial differences in skeletal maturation, which we would like to call either geographic or ethnic differences (Todd, 1931, Massé et al. 1963, Meredith 1968, Malcolm 1970, Malina 1970, Wingerd et al. 1974, Roche et al. 1975a, 1978).

References

ABBOTT, O. D. – TOWNSEND, R. O. – FRENCH, R. B. – AHMANN, C. F. (1950): Carpal and epiphyseal development: another index of nutritional status of rural school children. – Am. J. Phys. Anthrop. *79;* 69–81.

ACHESON, R. M. – FOWLER, G. B. – JAMES, M. D. (1962): Effect of improved care on the predicted adult height of undernourished children. – Nature *194;* 735–736.

ACHESON, R. M. – HEWITT, D. (1954): Oxford child health survey of stature and skeletal maturity in the preschool child. – Brit. J. Prev. Soc. Med. *8;* 59–65.

ANDERSEN, E. (1968): Skeletal maturation of Danish schoolchildren in relation to height, sexual development, and social conditions. – Acta Paediatr. Scand. (Suppl.) *185;* 1–33.

ASIEL, M. (1966): Considérations sur l'utilisation des méthodes de Greulich et Pyle et de Tanner pour l'évaluation de la maturation osseuse d'un échantillon de garçons âgés de 5 à 9 ans – *in: Compte rendu de la réunion des équipes chargées des études sur la croissance et le développement de l'enfant normal.* Stockholm, *1:* 53–59.

BALA, K. (1974): Hand-wrist ossification timing and skeletal maturity in deprived children of Chandigarh. Dissertation, Dept. Anthrop., Punjab University.

BAUGHAN, B. – DEMIRJIAN, A. – LEVESOUE, G.-Y. (1979): Skeletal maturity standards for French-Canadian children of school-age with a discussion of the reliability and validity of such measures. – Human Biology *51;* 353–370.

BAYLEY, N. – PINNEAU, S. R. (1952): Tables for predicting adult height from skeletal age: revised for use with the Greulich-Pyle hand standards. – J. Paediat. *40;* 423–441.

BEUNEN, G. (1985): Personal Communication.

BEUNEN, G. – CAMERON, N. (1980): The reproducibility of TW2 skeletal age assesments by a self-taught assessor. – Annals of Human Biology *7;* 155–162.

BIRBECK, J. A. (1984): Skeletal maturation in the early human factors. – *in:* Borms, J. – Hauspie, R. – Sand, A. – Susanne, C. Hebbelinck, M. (Eds) *Human Growth and Development*, pp. 353–363. Plenum Press.

BLANCO, R. – ACHESON, R. – CANOSA, C. – SALOMON, J. B. (1972): Retardation in appearance of ossification centres in deprived Guatemalian children. – Human Biology *44;* 525–535.

BRUCH, H. (1939): Obesity in childhood: physical growth and development of obese children. – Am. J. Dis. Childh. *58;* 457–484.

CHANG, K. – LEE, M. – LOW, W. – KWAN, E. (1963): Height and weight of Southern Chinese children. – Am. J. Phys. Anthrop. *21;* 497–509.

DEMIRJIAN, A. – GOLDSTEIN, H. – TANNER, J. M. (1973): A new system of dental age assessment. – Human Biology *45;* 211–227.

DESCAMPS, J. – BENCHEMSI, N. (1974): Maturation osseuse et conditions socio-économiques et culturelles (Étude transversale sur 4526 enfants et adolescents). – Rev. Pédiatrie, *10;* 143–151.

DE WIJN, J. F. (1953): Summarizing the survey and comments on the interrelationship between data obtained by medical inspection, biochemical investigations and diet of schoolchildren (1950–51) of three different social classes. – Verh. Inst. Prev. Geneesk. *22;* 167–183.

DOUGLAS, J. W. – BLOMFIELD, J. M. (1958): *Children under five.* G. Allen and Unwin. London.

DREIZEN, S. – SNODGRASSE, R. M. – PARKER, G. S. – CURRIE, C. – SPIES, T. D. (1954): Maturation of bone centers in hand and wrist of children with chronic nutritive failure; effect of dietary supplements of reconstituted milk solids. – Am. J. Dis. Childh. *87;* 429–439.

DREIZEN, S. – SNODGRASSE, R. M. – WEBB-PEPLOE, H. – SPIES, T. D. (1958): The retarding effect of protacted undernutrition on the appearance of the postnatal ossification centers in the hand and wrist. – Human Biology *30;* 253–264.

FALKNER, F. (1955): *Une base commune de recherches pour les études longitudinales sur la croissance de l'enfant*: Centre International de l'Enfance, Paris.

FALKNER, F. (1958): Skeletal maturation; an appraisal concept and method. – Am. J. Phys. Anthrp. *16;* 381–396.

FRISANCHO, A. R. – GARN, S. M. – ASCOLI, W. (1970): Childhood retardation resulting in reduction of adult body size due to lesser adolescent skeletal delay. – Am. J. Phys. Anthrop *33;* 325–336.

FRISK, M. – WIDHOLM, O. – TENHUNEN, T. – HORTLING, H. (1966): Overweight in adolescents – a complex problem. – Ann. Paediatr. Fenn. *12;* 234–245.

GARN, S. M. – CLARK, D. C. (1975): Nutrition, growth, development and maturation: findings from the ten-state nutrition survey of 1968–1970. – Pediatrics *56;* 306–319.

GARN, S. M. – HASKELL, J. A. (1959): Fat and growth during childhood. – Science *130;* 1711.

GARN, S. M. – HASKELL, J. A. (1960): Fat thickness and developmental status in childhood and adolescence. – Am. J. Dis. Childh. *99;* 746–751.

GARN, S. M. – ROHMANN, C. G. (1962): Parent-child similarities in hand-wrist ossification. – Am. J. Dis. Childh. *103;* 603–607.

GARN, S. M. – ROHMANN, C. G. – BLUMENTHAL, T. (1966): Ossification sequence, polymorphism and sexual dimorphism in skeletal development. – Amer. J. Phys. Antrop. *24;* 101–115.

GARN, S. M. – ROHMANN, C. G. – DAVIES, A. A. (1963): Genetics of hand-wrist ossification. – Am. J. Phys. Anthrop. *21;* 33–40.

GARN, S. M. – ROHMANN, C. G. – RONINOW, B. (1961): Increments in hand-wrist ossification. – Am. J. Phys. Anthrop. *19;* 45–53.

GARN, S. M. – SANDUSKY, S. T. – ROSEN, N. N. – TROWBRIDGE, F. (1973): Economic impact on postnatal ossification. – Am. J. Phys. Anthrop. *38;* 1–4.

GRAFFAR, M. (1958): La nécessité d'études longitudinales de la croissance de l'enfant normal. – Acta Paed. Belgica *4;* 171–180.

GRAFFAR, M. (1971): L'influence des facteurs sociaux sur la croissance et le développement de l'enfant. – Les Carnets de l'Enfance *15;* 23–31.

GPEULICH, W. W. – CRISMON, C. S. – TURNER, M. L. (1953): The physical growth and development of children who survived the atomic bombing of Hiroshima or Nagasaki. – J. Pediatr. *43;* 121–145.

GREULICH, W. W. – PYLE, S. I. (1959): *Radiographic atlas of skeletal development of hand and wrist.* – Stanford University Press, California.

HAUSPIE, R. – SUSANNE, C. – ALEXANDER, F. (1977): Maturational delay and temporal growth retardation in asthmatic boys. – J. Allerg. Clin. Immunol. *89;* 200–206.

HAUSPIE, R. – WACHHOLDER, A. –BARON, G. – CANTRAINE, F. – SUSANNE, C. – GRAFFAR, M. (1980): A comparative study of the fit of four different functions to longitudinal data of growth in height of Belgian girls. – Annals of Human Biology *7;* 347–358.

HELM, S. (1979): Skeletal maturity in Danish schoolchildren assessed by the TW2 method. – Am. J. Phys. Antrop. *51;* 345–351.

HEWITT, D. – ACHESON, R. M. (1961): Some aspects of skeletal development through adolescence. I and II. – Am J. Phys. Anthrop. *19;* 213–221, and 321–331.

HEWITT, D. – WESTROPP, C. K. – ACHESON, R. M. (1955): Oxford child health survey: effect of childish ailments on skeletal development. – Br. J. Prev. Soc. Med. *9;* 179–186.

JOHNSTON, F. E. (1964a): Individual variation in the rate of skeletal maturation between five and eighteen years. – Child. Devel. *35;* 75–80.

JOHNSTON, F. E. (1964b): The relationship of certain growth variables to chronological and skeletal age. – Human Biology *36;* 16–27.

JOHNSTON, F. E. (1971): The use of Greulich-Pyle method in a longitudinal growth study. – Am. J. Phys. Anthrop. *34;* 353–358.

JOHNSON, G. F. – DORST, J. P. – KUHN, J. P. – ROCHE, A. F. – DAVILLA, G. H. (1973): Reliability of skeletal age assessments. – Am. J. Roentgenelogy, Radium Therapy and Nuclear Medicine *118;* 320–327.

JOHNSTON, F.E. – SHARKO, J. – CRAVIOTO, J. – DE LICARDIE, E. (1984): Growth and skeletal maturation of Mexican children 4 to 7 years, with and without diagnoses of chronic protein-energy malnutrition. – *in:* Borms, J. – Hauspie, R. – Sand, A. – Susanne, C. – Hebbelinck, M. (Eds). *Human Growth and Development.* pp. 585–595. Plenum Press.

KOPCZYNSKA-SIKORSKA, J. (1964): Détermination radiologique de la maturation osseuse. – Ann. Radiol. *7;* 308–314.

KOPCZYNSKA-SIKORSKA, J. – NLEDZWIECKA, Z. (1984): Skeletal maturity in children brought-up under good socio-economic conditions. – *in:* Borms, J. – Hauspie, R. – Sand, A. – Susanne, C. – Hebbelinck, M. (Eds) *Human Growth and Development.* pp. 397–405. Plenum Press.

KRISTMUNDOTTIR, F. – BURWELL, R. G. – HARRISON, M. H. – MARSHALL, W. A. (1984a): Bone age retardation at the hand and wrist in children with Perthes' disease – *in:* Borms, J. – Hauspie, R. – Sand, A. – Susanne, C. – Hebbelinck, M. (Eds) *Human Growth and Development.* pp. 365–374. Plenum Press.

KRISTMUNDOTTIR, F. – BURWELL, R. G. – MARSHALL, W. A. – SMALL, P. (1984b): Cross-sectional study of skeletal maturation in normal children from Nottingham and London. – Annals of Human Biology, *11;* 133–139.

LAMPL, M. – JOHNSTON, F. E. – MALCOLM, L. A. (1978): The effects of protein supplementation on the growth and skeletal maturation of New Guinean school children. – Annals of Human Biology *5;* 219–227.

LOW, W. – CHAN, S. – CHANG, K. – LEE, M. (1964): Skeletal maturation of Southern Chinese children. – Child Devel. *35;* 1313–1336.

McNAIR, V. – ROBERTS, L. J. (1938): Effects of a milk supplement on the physical status of institutional children II. Ossification of the bones of the wirst. – Am. J. Dis. Childh. *56;* 494–509.

MALCOLM, L. A. (1970): Growth and development of the Bundi child of the New Guinea highlands. – Human Biology *42;* 293–328.

MALINA, R. M. (1970): Skeletal maturation studied longitudinally over one year in American Whites and Negroes six through thirteen years of age. – Human Biology *42;* 377–390.

MARESH, M. M. (1966): Changes in tissues widths during growth. Roentgenographic measurements of bone, muscle and fat widths from infancy through adolescence. – Am. J. Dis. Child. *3;* 142–155.

MARSHALL, W. A. (1974): Interrelationships of skeletal maturation, sexual development and somatic growth in man. – Annals of Human Biology *1;* 29–40.

MARSHALL, W. A. – TANNER, J. M. (1969): Variations in the pattern of pubertal changes in girls. – Arch. Dis. Childh. *44;* 491–303.

MARSHALL, W. A. – TANNER, J. M. (1970): Variations in the pattern of pubertal changes in boys. – Arch. Dis. Childh. *45;* 13–23.

MARTORELL, R. – YARBROUGH, C. – KLEIN, R. E. – LECHTIG, G. (1979): Malnutrition, body size, and skeletal maturation: interrelationships and implications for catch-up growth. – Human Biology *51;* 371–389.

MASSÉ, G. – HUNT, E. E. (1963): Skeletal maturation of the hand and wrist in West African children. – Human Biology *35;* 3–25.

MAZESS, R. B. – CAMERON, N. (1971): Skeletal growth in school children: maturation and bone mass. – Am. J. Phys. Anthrop. *35:* 399–408.

MEREDITH, H. V. (1968): Body size of contemporary groups of preschool children studied in different parts of the world. – Child Develop. *39;* 335–377.

NEYZI, O. – GUNÖZ, H. – UZEL, T. – CELENK, A. – OZSARFATI, J. – SAIT, R. – YENERER, N. (1984): Bone maturation in Turkish newborns – *in:* Borms, J. – Hauspie, R. – Sand, A. – Susanne, C. – Hebbelinck, M. (Eds) *Human Growth and Development.* pp. 375–385. Plenum Press.

REA, J. V. (1971): Social and economic influences on the growth of pre-school children in Lagos. – Human Biology *43;* 46–63.

ROCHE, A. F. (1978): Bone growth and maturation. – *in:* Falkner, F. – Tanner, J. M. (Eds) *Human Growth and Development,* Vol. *2; Postnatal Growth.* pp. 317–355. Balliere Tindall, London.

ROCHE, A. F. – DAVILLA, G. H. – EYMANN, S. L. (1971): A comparison between Greulich-Pyle and Tanner-Whitehouse assessments of skeletal maturity. – Radiology *98;* 273–280.

ROCHE, A.. F. – DAVILLA, G. H. – PASTERNACK, B. A. – WALTON, M. J. (1970): Some factors influencing the replicability of assessments of skeletal maturity. – Am. J. Roentgenology, Radium Therapy and Nuclear Medicine *109;* 307–321.

ROCHE, A. F. – ROBERTS, J. – HAMILL, P. V. V. (1975a): *Skeletal maturity of children 6–11 years: social, geographic, area and socio-economic differentials.* – DHEW publication n^{o} (HRA) 76–1631, US. Dept. of Health, 79 pp.

ROCHE, A. F. – ROBERTS, J. – HAMILL, P. V. V. (1978): *Skeletal maturity of youths 12–17 years: racial, geographic area, and socio-economic differentials.* – DHEW publication n^{o} (PHS) 79–1654, US. Dept. of Health, 98 pp.

ROCHE, A. F. – WAINER, J. – THISSEN, D. (1975b): *Skeletal maturity. The knee joint as a biological indicator.* Plenum Press.

ROCHE, A. F. – WAINER, H. – THISSEN, D. (1974): The Roche-Wainer-Thissen method for predicting adult stature. – *in: Compte-rendu de la XII^{o} réunion des équipes chargées des études sur la croissance et le développement de l'enfant normal,* pp. 50–62. Centre International de l'Enfance, Paris.

SEMPÉ, M. (1968): De quelques facteurs extrinsèques agissant sur la croissance. – Rev. Hyg. Méd. Soc. *169;* 219–262.

SIMMONS, K. – GREULICH, W. W. (1943): Menarcheal age and the height, weight and skeletal age of girls aged 7 to 17 years. – J. Pediatr. *22;* 518–548.

SNODGRASSE, R. M. – DREIZEN, S. – CURRIE, C. – PARKER, G. S. – SPIES, T. D. (1955): The association between anomalous ossification centers in the hand skeleton, nutritional status and the rate of skeletal maturation in children five to fourteen years of age. – Am. J. Roentgenol. *74;* 1037–1048.

SPIES, T . D. – DREIZEN, S. – SNODGRASSE, R. M. – Arnett, C. M. – WEBB-PEPLOE, H. (1959): Effect of dietary supplement of nonfat milk on human growth failure: comparative response in undernourished children and in undernourished adolescents. – Am. J. Dis. Childh. *98;* 187–197.

TANNER, J. M. (1962): *Growth at adolescence.* – Blackwell, Oxford.

TANNER, J. M. – WHITEHOUSE, R. H. – HEALY, M. J. R. (1962): *A new system for estimating skeletal maturity from the hand and wrist, with standards derived from a study of 2600 healthy British children.* Centre International de l'Enfance. Paris.

TANNER, J. M. – WHITEHOUSE, R. H. – MARSHALL, W. A. – HEALY, M. J. R. – GOLDSTEIN, H. (1975): *Assessment of skeletal maturity and prediction of adult height (TW2 method).* – Academic Press.

TIISALA, R. – KANTERO, R. L. – BACKSTROM, L. (1966): The appearance pattern of skeletal epiphyses among Finnish children during the first five years of life. – Ann. Paediatr. Fenn. *12;* 64–72.

TIISALA, R. – KANTERO, R. L. – BACKSTROM, L. – HALLMAN, N. (1968): Assessment of skeletal age in the first five years of life. – Ann. Paediat. Fenn. *14;* 47–51.

TIISALA, R. – KANTERO, R. L. – BACKSTROM, L. – HALLMAN, N. (1969): A mixed longitudinal study on skeletal maturation in healthy finnish children aged 1 to 5 years. – Human Biology *41;* 560–570.

TIISALA, R. – KANTERO, R. L. – TAMMINEN, T. (1971): A mixed longitudinal study on skeletal maturation in healthy finnish children aged 5 to 10 years. – Human Biology. *43;* 224–236.

TODD, T. W. (1931): Differential skeletal maturation in relation to sex, race, variability and disease. – Child Develop. *2;* 49–65.

VAN VANRÓOIJ-YSSELMUIDEN, M. E. – VAN IPENBURG, A. (1978): Mixed longitudinal data on skeletal age from a group of Dutch children living in Utrecht and surroundings. – Annals of Human Biology *4;* 359–380.

WACHHOLDER, A. – CANTRAINE, F. (1975): Étude de la puberté. Paramètres somatiques (taille-poids) et sociaux des 56 filles de l'échantillon belge. – *in: Compte-rendu de la XII^{o} réunion des équipes chargées des études sur la croissance et le développement de l'enfant normal.* pp 64–76. Centre International de l'Enfance, Paris.

WENZEL, A. – MELSEN, B. (1982): Replicability of assessing radiographs by the Tanner and Whitehouse-2 method. – Human Biology *54;* 575–581.

WIDDOWSON, H. E. M. – McCANCE, R. A. (1954): Studies on the nutritive value of bread on the effect of variations in the extraction rate of flour on the growth of undernourished children. – Med. Res. Counc. Spec. Rep. Ser. n^{o} 287.

WINGERD, J. – PERITZ, E. – SPROUL, A. (1974): Race and stature differences in the skeletal maturation of the hand and wrist. – Annals of Human Biology. *1;* 201–209.

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APPENDIX 1

Age	P3	P10	P25	P50	P75	P90	P97
			Centiles of TW2 MATURITY SCORES for age in Belgian boys				
1.0	67.36	80.92	94.59	109.85	125.11	138.78	152.34
2.0	107.12	122.19	137.38	154.33	171.28	186.47	201.54
3.0	141.44	157.19	173.07	190.79	208.51	224.39	240.14
4.0	168.60	188.77	209.10	231.79	254.48	274.81	294.98
5.0	179.85	210.66	241.73	276.39	311.05	342.12	372.93
6.0	222.72	259.54	296.68	338.11	379.54	416.68	453.50
7.0	255.25	296.60	338.30	384.82	431.34	473.04	514.39
8.0	365.67	399.08	432.77	470.35	507.93	541.62	575.03
9.0	413.95	450.31	486.98	527.88	568.79	605.45	641.81
10.0	456.67	499.22	542.12	589.98	637.84	680.74	723.29
11.0	523.95	566.88	610.16	658.45	706.74	750.02	792.95
12.0	583.20	629.70	676.59	728.90	781.21	828.10	874.60
13.0	656.38	705.37	754.77	809.88	864.99	914.39	963.38
14.0	771.34	808.55	846.06	887.92	929.78	967.29	1000.00
15.0	879.26	900.12	921.15	944.61	968.07	989.10	1000.00
			Centiles of RUS MATURITY SCORES for age in Belgian Boys				
2.0	6.52	23.12	39.86	58.54	77.22	93.96	110.56
3.0	52.10	67.01	82.05	98.82	115.59	130.63	145.54
4.0	95.85	106.68	117.61	129.80	141.99	152.92	163.75
5.0	112.39	124.47	136.64	150.22	163.80	175.97	188.05
6.0	136.47	149.10	161.83	176.03	190.23	202.96	215.59
7.0	142.86	159.84	176.96	196.06	215.16	232.28	249.26
8.0	185.89	201.66	217.56	235.30	253.04	268.94	284.71
9.0	206.02	223.48	241.09	260.73	280.37	297.98	315.44
10.0	219.11	240.78	262.63	287.00	311.37	333.22	354.89
11.0	241.20	265.77	290.55	318.19	345.83	370.61	395.18
12.0	248.33	285.14	322.26	363.67	405.08	442.20	479.01
13.0	259.38	319.03	379.18	446.29	513.40	573.55	633.20
14.0	311.03	388.31	466.23	553.17	640.11	718.03	795.31
15.0	418.20	502.02	586.54	680.84	775.14	859.66	943.48
			Centiles of CARPAL MATURITY SCORES for age in Belgian Boys				
3.0	149.02	165.64	182.41	201.11	219.81	236.58	253.20
4.0	143.97	172.46	201.18	233.23	265.28	294.00	322.49
5.0	140.76	186.20	232.03	283.15	334.27	380.10	425.54
6.0	171.28	230.81	290.84	357.81	424.78	484.81	544.34
7.0	226.45	288.37	350.81	420.47	490.13	552.57	614.49
8.0	355.03	411.66	468.75	532.45	596.15	653.24	709.87
9.0	434.35	491.72	549.56	614.10	678.64	736.48	793.85
10.0	515.93	575.58	635.72	702.82	769.92	830.06	889.71
11.0	629.09	680.76	732.86	790.98	849.10	901.20	952.87
12.0	721.63	765.73	810.20	859.81	909.42	953.89	997.99
13.0	806.56	842.27	878.27	918.44	958.61	994.61	1000.00
14.0	897.52	920.31	943.30	968.94	994.58	1000.00	1000.00
15.0	968.08	976.43	984.85	994.25	1000.00	1000.00	1000.00

APPENDIX 2

Age	P3	P10	P25	P50	P75	P90	P97
Centiles of TW2 BONE AGE for age in Belgian boys							
1.0	0.95	1.14	1.33	1.55	1.77	1.96	2.15
2.0	1.22	1.55	1.88	2.24	2.60	2.93	3.26
3.0	1.96	2.29	2.62	2.99	3.36	3.69	4.02
4.0	2.62	2.99	3.37	3.80	4.23	4.61	4.98
5.0	2.88	3.43	3.99	4.61	5.23	5.79	6.34
6.0	3.70	4.33	4.97	5.69	6.41	7.05	7.68
7.0	4.32	5.01	5.70	6.48	7.26	7.95	8.64
8.0	6.21	6.74	7.28	7.88	8.48	9.02	9.55
9.0	7.06	7.61	8.17	8.79	9.41	9.97	10.52
10.0	7.77	8.40	9.03	9.73	10.43	11.06	11.69
11.0	8.79	9.41	10.03	10.73	11.43	12.05	12.67
12.0	9.63	10.30	10.99	11.75	12.51	13.20	13.87
13.0	10.57	11.35	12.13	13.00	13.87	14.65	15.43
14.0	12.10	12.80	13.51	14.30	15.09	15.80	16.50
15.0	13.70	14.27	14.84	15.47	16.10	16.67	17.24
Centiles of RUS BONE AGE for age in Belgian Boys							
2.0	1.31	1.62	1.94	2.29	2.64	2.96	3.27
3.0	1.95	2.32	2.69	3.10	3.51	3.88	4.25
4.0	2.90	3.23	3.57	3.95	4.33	4.67	5.00
5.0	3.32	3.74	4.15	4.62	5.09	5.50	5.92
6.0	4.07	4.53	5.00	5.52	6.04	6.51	6.97
7.0	4.29	4.92	5.55	6.26	6.97	7.60	8.23
8.0	5.91	6.48	7.06	7.71	8.36	8.94	9.51
9.0	6.73	7.33	7.94	8.61	9.29	9.89	10.49
10.0	7.24	7.96	8.69	9.51	10.33	11.06	11.78
11.0	8.08	8.86	9.66	10.54	11.42	12.22	13.00
12.0	8.93	9.83	10.74	11.75	12.76	13.67	14.57
13.0	10.48	11.35	12.23	13.22	14.21	15.09	15.96
14.0	12.35	13.05	13.75	14.53	15.31	16.01	16.71
15.0	13.71	14.31	14.92	15.59	16.27	16.87	17.47
Centiles of CARPAL BONE AGE for age in Belgian boys							
3.0	2.00	2.46	2.92	3.43	3.94	4.40	4.86
4.0	2.40	2.95	3.51	4.13	4.75	5.31	5.86
5.0	3.01	3.66	4.32	5.06	5.80	6.46	7.11
6.0	3.22	4.06	4.91	5.85	6.80	7.64	8.48
7.0	4.30	5.06	5.82	6.67	7.52	8.28	9.04
8.0	6.00	6.63	7.26	7.96	8.66	9.29	9.92
9.0	6.88	7.51	8.14	8.84	9.54	10.17	10.80
10.0	7.70	8.37	9.06	9.82	10.58	11.27	11.94
11.0	8.84	9.48	10.13	10.85	11.57	12.22	12.86
12.0	9.81	10.43	11.05	11.75	12.45	13.07	13.69
13.0	10.51	11.23	11.96	12.78	13.60	14.33	15.05
14.0	11.95	12.56	13.18	13.87	14.56	15.18	15.79
15.0	13.63	13.97	14.32	14.70	15.08	15.43	15.77