



SKELETAL MATURITY AND FACIAL GROWTH ASSESSMENT *

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INTRODUCTION

The planning of orthodontic treatment usually requires an assessment of the patient's current maturity status, past patterns of development and, in particular his future growth potential. For an evaluation of this nature, observations must be obtained and appraised against a knowledge of human growth patterns, the processes of skeletal and dental maturation and the many determinants, genetic and otherwise, that influence them.

This paper outlines some methods that will enable the clinician to make a reasonable assessment of the child's maturity status and future growth potential. Because the average practitioner will have neither the time nor the facilities to study child growth in detail, the procedures discussed are limited to those that can be carried out adequately in most dental offices.

CLINICAL ANALYSIS

Human growth, in common with most biological processes, displays wide variability, particularly in its timing and intensity. Marked differences in the onset of maturation events make chronological age a poor indicator of a child's developmental status. At any given age, some children will be advanced skeletally, some will conform to average trends while others will be retarded depending on their genetic makeup, nutritional background and other environmental factors.

Notwithstanding the wide variability in the timing of growth events, the sequence of maturation is relatively constant in all children. For example, long bones of the body show a deceleration in growth velocity from birth and a marked but temporary spurt in velocity at the time of puberty. A knowledge of the timing and sequence of growth events, particularly around adolescence, will be useful in planning orthodontic treatment.

The objective of a clinical analysis, then, is to appraise the present developmental status of the patient and to assess his future growth potential as it relates to treatment. An assessment based on observations obtained on one occasion will be less reliable than one derived after the examination of serial records obtained over a number of years. Nevertheless, single examination records can yield valuable information when analysed sensibly.

It is important to differentiate between observations obtained at single examinations and those forming part of a longitudinal series. Two terms, used at the Orthodontic Department, Royal Dental College, Copenhagen, will be used to clarify this differentiation. If the clinical analysis is based on a single set of records it will be referred to as a **morphologic analysis**; if based on more than one set of records, the term **growth analysis** is more appropriate.

Morphologic Analysis.

A morphologic analysis is concerned with size, shape and maturity at the time of examination. It is therefore a static analysis representing one instant in the growing child's developmental history. A morphologic analysis provides no evidence of past events and is a poor basis for predicting future progress unless accompanied by other information. In many instances, however, the clinician must rely on observations made at a single examination to gain some indication of future development. Fortunately, many standards are now available for assessing the child's status in relation to other children of the same sex, age and ethnic origin.

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A typical morphologic analysis would include estimation of dental maturity based on published standards of tooth formation and eruption, a general physical appraisal using stature and perhaps other body measurements for comparison with population standards, and an estimation of the child's skeletal maturity using criteria based on ossification stages of centres in the hand and wrist. In addition, cephalometric roentgenograms would provide an evaluation of facial morphology. Recordings of parental stature and facial type will also be useful.

Growth analysis.

Serial records collected with care over a number of years provide the basis for a more detailed appraisal of the amount, direction and rate of growth in the body and, in particular, the craniofacial structures. By following progress over a time the clinician is aware of the timing and sequence of growth events and can assess the future growth potential more objectively.

In most instances the orthodontist will not be able to carry out a true growth analysis at the commencement of treatment. However, if serial recordings are made at regular intervals during the course of treatment the additional information will be useful and could lead to modifications in treatment. The advantages of serial records are so great that the clinician should commence their acquisition as early as practical. Very often family, school or medical records of stature, weight, menarche and illness will be available to assist the clinician in his assessment.

CLINICAL RECORDS

At the time of examination, whether it be the first occasion or one in a series of examinations, records should be obtained to enable appraisal of dental maturity, craniofacial relationships and physical and skeletal maturity. As serial records accumulate, the child's progress towards maturity will become more evident. Supplementing these records will be the usual oral and dental examinations, intra-oral roentgenographic survey, personal and family histories.

Dental maturity.

Dental maturity can be rated according to pre-eruptive or post-eruptive stages of development. Post-eruptive status is estimated by charting the timing and sequence of tooth emergence or, if serial observations are unavailable, by charting the teeth present at examination. Standards for tooth eruption in Australian

children have been published by Roche, Barkla and Maritz¹ for the deciduous teeth and by Halikis,² Carr³ and Gates⁴ for permanent teeth. High and low percentile ratings for each tooth indicate the range of variability in the timing of tooth emergence.

The rating of pre-eruptive stages of dental development can be of more practical value than the simple charting of teeth present at examination. Methods for assessing the developmental stages of teeth from lateral jaw roentgenograms, and the application of standards of crown and root formation in clinical dentistry are given in several publications stemming from the Forsyth Dental Infirmary. 5, 6, 7, 8, 9, 10, 11, 12, 13 The longitudinal standards of tooth formation referred to are based on the time of attainment of several defined stages of crown and root formation in permanent teeth as observed on lateral jaw roentgenograms of North American white children. Accompanying charts show the range of variability for each stage and the time interval between stages. By comparing the stages of tooth formation in the patient with the population standards it is possible to determine if the child is advanced or retarded in dental maturity and to predict, within limits, the time of reaching later stages of tooth formation and eruption.

Craniofacial morphology.

Standardized lateral and postero-anterior roentgenograms of the head provide material from which measurements are obtained for craniofacial analysis. The measurements may be recorded from film tracings or, preferably, directly from the roentgenograms using transparent overlays in the manner described by Björk and Solow.¹⁴ If a reader-digitizer is available recordings of co-ordinate values for specified reference points can be obtained speedily and the required linear, angular and proportionate values computed by trigonometric functions.^{15, 16, 17} Steps must be taken to minimize sources of experimental error and, in addition, linear dimensions should be scaled to compensate for roentgenographic enlargement.

Surprisingly few sex-specific, age-specific standards for cephalometric variables have been derived from large samples. In contrast numerous analytic methods depending on the relationships between lines and angles have been proposed for clinical use.^{18, 19, 20} Measurements obtained from roentgenograms can be compared with group mean values, with percentile charts, or plotted on standard deviation polygons. Alternatively, an overall assessment of facial

morphology can be made by matching the roentgenograms or tracings against transparent templates constructed according to mean values or by plotting the reference points on a standard mesh diagram according to the method of Moorrees and Le Bret.²¹ Scaling must be the same for roentgenographic dimensions and the standard used for comparison.

At the present time, craniofacial growth can be analysed most accurately from serial roentgenograms obtained from subjects with metallic pins implanted in the jaws to provide stable points of registration.^{22, 23} Internal and external remodelling occurs during the growth of bones and analytic methods based on the assumption that reference planes and points remain unchanged with age lead to inaccurate assessments of growth rates and directions. However the registration of serial films on relatively stable bony structures located in the anterior cranial fossa increases the value of a growth analysis but the accuracy is less than that obtainable with fixed implants.

Physical analysis.

Anthropologists, pediatricians and research workers in the field of human growth use a variety of body measurements to assess physical status. Observations obtained over a number of years provide a permanent and progressive record of physical change during the growing period. This discussion is limited to one of many standard measurements, namely stature or body length.

Although stature is a complex variable, made up of several smaller components such as length of leg, length of trunk and head height, it displays the typical fluctuations during growth that are recordable in a single long bone such as the radius. Because body posture changes from time to time during the day stature is most consistently recorded with the child in a horizontal position. However, anthropometers are unlikely to be available in the orthodontic clinic and stature can be measured with the child standing against an accurate wall scale. Care should be taken to standardize the measuring technique.

When stature increments are plotted against age the resulting velocity curve shows that the growth rate decreases from birth but characteristically displays one minor and one major upward fluctuation indicative of periodic growth acceleration. The first acceleration is a small one, not always present, that occurs at about 6-8 years in Caucasian children; this is known as a juvenile or **mid-growth spurt**. Before puberty, at about 10½ years in girls and 12½ years in boys the curve reaches a depression known as the **pre-puberal minimum** when the growth rate is lowest since birth. With increasing age, the velocity curve shows a sharp upward reversal until it reaches the **puberal maximum** at about 11½-12½ years in girls and 13-14 years in boys.^{24, 25} This upward trend in the velocity curve takes place at the time of the **adolescent growth spurt**. Once the peak is reached, growth velocity decelerates rapidly

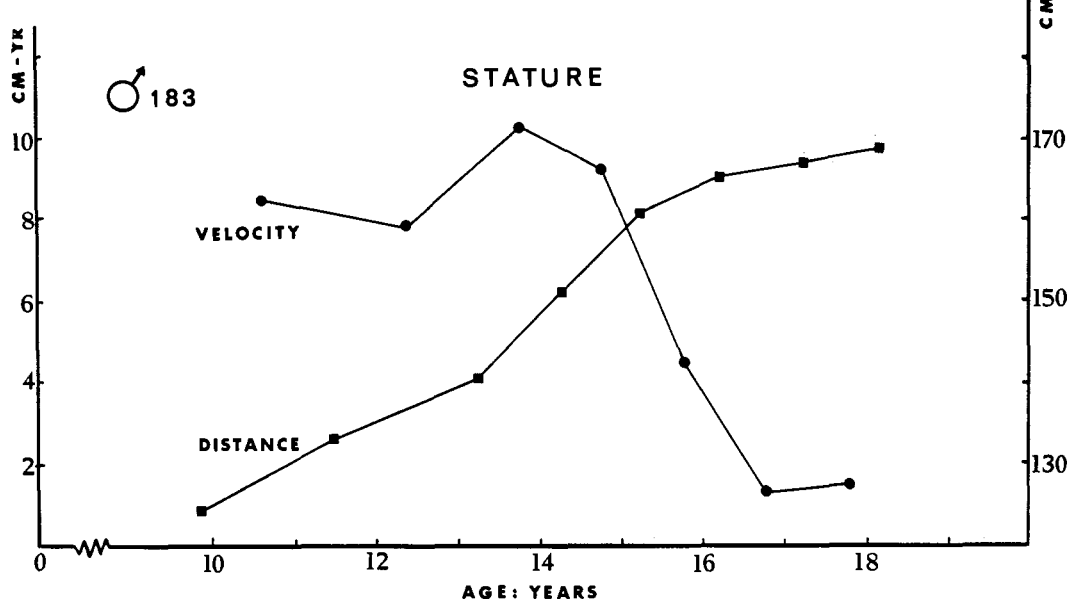


Fig. 1—Growth in stature showing distance and velocity around adolescence.

until adult stature is reached with epiphyseal closure in the long bones. Figure 1 illustrates a typical growth curve for stature increments during the circum-puberal years.

Although the adolescent spurt occurs in all children there is marked variability in the time of onset, the intensity of the growth spurt and its duration. The spurt begins on the average about 2 years earlier in girls reaching a peak velocity of some 8 cm. per year in contrast to boys who peak at an average of about 10 cm. per year.

When longitudinal records of stature are not available the child's physical status must be assessed from one observation by reference to suitable standards for children of the same age, sex and ethnic origin. However, such a comparison relates to the time of examination only and gives no indication of past or future growth trends. For example, a child whose height lies within a low percentile range for his chronological age may be a late maturer who will eventually accelerate to average or even above-average stature. Alternatively he may be a naturally small child who will remain below average in stature throughout growth.

Standard height tables have been compiled for Australian children²⁶ who show no great differences in their average growth patterns from British and North American white children. Consequently, standards from any of these populations would lead to reasonably accurate assessments of physical status in relation to group means.

A useful set of height charts were prepared from Fels material by Garn and Rohmann.^{27,28} The first chart, giving parent-specific standards for height in North American white children, takes into account the genetic association in stature between sibling and parents. The chart records the average stature of children according to chronological age and mid-parent stature, that is the average stature of mother and father. In the event that the father's stature is unknown, a second chart gives an estimated mid-parent stature according to the mother's known stature and a classification of the father's stature as short, average, tall or unknown. The estimated mid-parent value obtained is then used to enter the parent-specific chart according to the child's chronological age.

The parent-specific charts are based on large numbers of subjects and, being constructed recently, take into account secular trends in stature. Although these standards refer to a specific North American population

they can be used for Australians with some confidence until locally derived values are available.

RELATION OF HEAD GROWTH TO GENERAL BODY GROWTH

The bones of the craniofacial skeleton are known to grow with increased velocity at about the time that peak statural growth occurs. In the cranial vault an adolescent spurt is measurable in the dimensions of length, breadth and circumference even though up to 96 per cent of adult size has been attained by the age of 10.24. Increments of head length and breadth reach a maximum of some 2 mm. per year at adolescence and are detectable only when plotted on an enlarged scale. A large part of the adolescent growth in cranial vault dimensions is probably due to surface accretion that takes place at this time.^{29,30} In addition, forward growth of the forehead can be accounted for by frontal sinus enlargement at adolescence.

Nanda,³¹ using data from longitudinal cephalograms, showed that most facial dimensions displayed an adolescent spurt in growth reaching a peak a few months after stature. In the mandible the adolescent spurt is delayed slightly and tends to be more intense than in other facial bones. The ramus in particular shows a large growth spurt at adolescence. Facial growth at puberty brings about marked changes in the profile. Both jaws are displaced forwards but because mandibular displacement is greater, the profile becomes straighter, the chin more prominent and the incisors more upright. Concurrently the nose enlarges at adolescence.

Knowing that facial dimensions undergo an adolescent spurt shortly after the peak stature velocity, the clinician can use growth observations to predict when facial growth is likely to be most intense. If the patient has been examined a number of times and several consecutive measurements of stature obtained, it is possible to recognize the pre-puberal minimum and so anticipate the adolescent spurt. Very often family records of stature are available to assist the clinician, but in the absence of longitudinal recordings, other developmental events can be related to the stature velocity curve to provide a reasonable estimate of physical status.

MATURITY INDICATORS

Hand and wrist ossification.

Because of wide individual variation in the timing of growth, chronological age is a poor indicator of a child's skeletal maturity. In

contrast, assessments of skeletal age based on the appearance of developmental events in the skeleton are more reliable and objective. Although numerous bones of the body can be rated for skeletal assessment, the 30 centres of ossification observed in the hand and wrist are most commonly used. The hand and wrist film is easily obtained, most centres of ossification are readily visualized and with experience fairly consistent skeletal age ratings

can be made. It has been shown that the slight differences in ossification timing of left and right bones are not significant so that either hand can be radiographed for assessment.³² If the entire fore-arm is included in the standard roentgenographic assessment, serial measurements of the radius can be used in place of stature recordings to indicate velocity.

Several systems of skeletal rating have been proposed, the most popular being the so-called

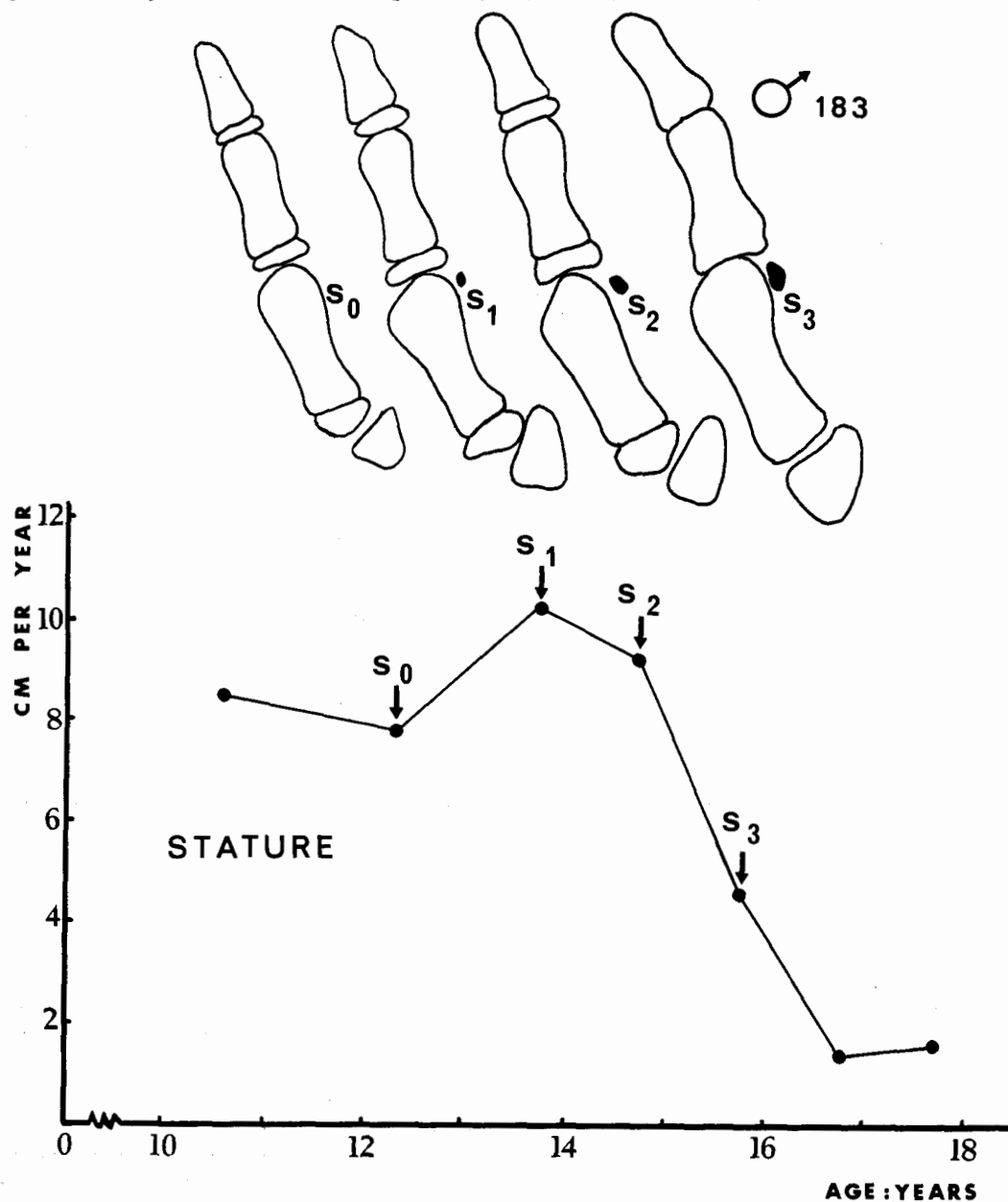


Fig. 2a—The relationship between ossification of the adductor sesamoid and statural growth around adolescence. In this subject initial ossification of the sesamoid occurred during the same year as peak statural velocity.

Atlas Method. This method involves the use of the Greulich-Pyle Atlas³³ of hand and wrist plates which are matched against the patient's film until the plate closest in ossification status is selected; this plate gives the child's skeletal age. Although the Greulich-Pyle standards are based on North American white children it has been shown that they can be used without change of scale to assess Melbourne children.³⁴

Skeletal ossification and its assessment are detailed in several texts on the subject, 24, 35, 36, 37 although in most instances the orthodontist will not require such detailed assessments.

The Clinician can obtain valuable information by observing ossification events that take place on the average around puberty. Of these, the adductor sesamoid, situated at the metacarpal-phalangeal joint of the thumb, is con-

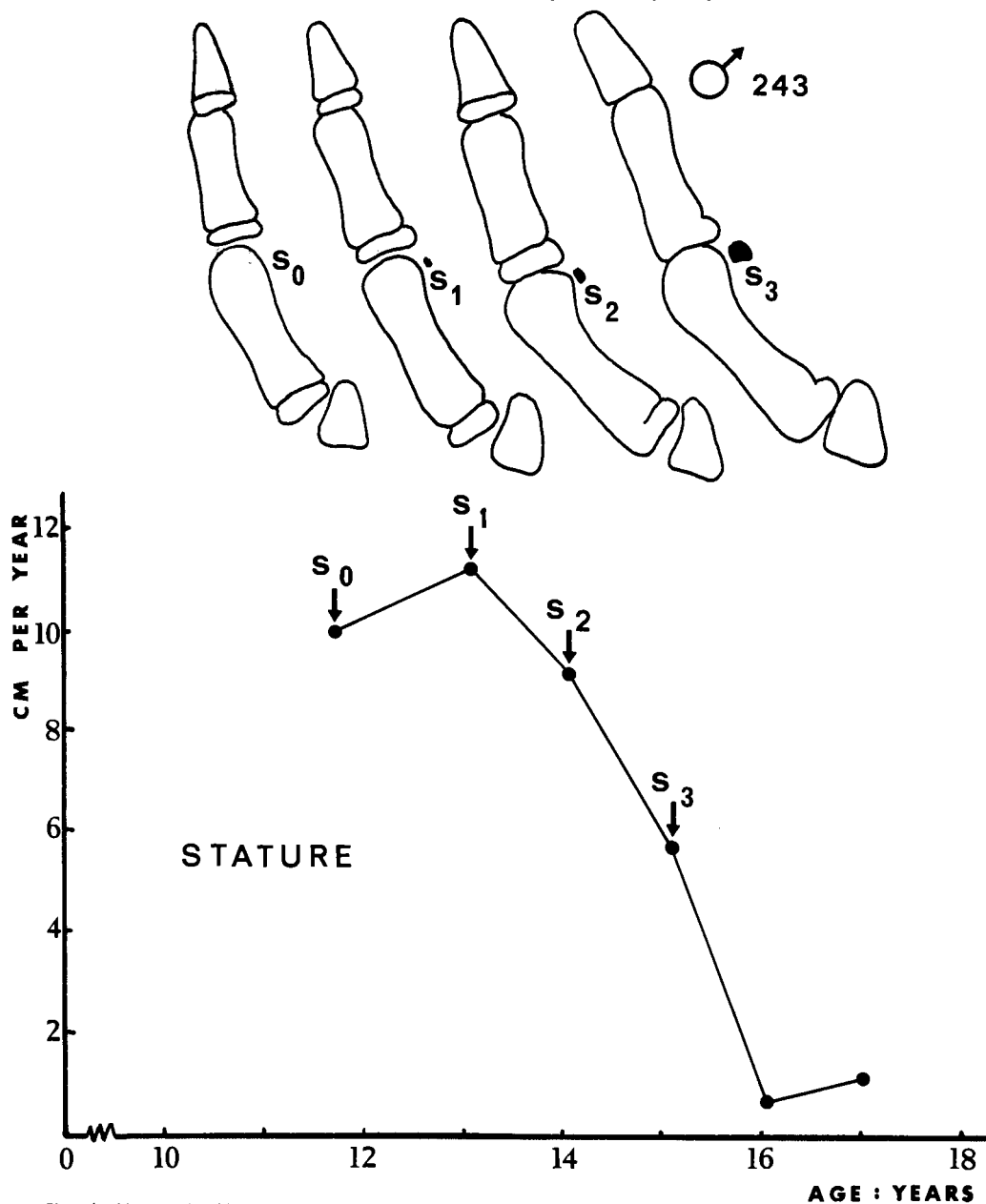


Fig. 2b—The relationship between ossification of the adductor sesamoid and stature growth around adolescence. In this subject initial ossification of the sesamoid occurred during the same year as peak stature velocity.

sistently present and readily visualized for clinical assessment. Garn, Rohmann and Silverman³⁷ found that the mean age of appearance of the adductor sesamoid was 12.76 years in boys and 10.72 years in girls. In Danish children, Björk and Helm²⁵ reported mean values for appearance of the sesamoid of 13.25 years in boys and 11.5 years in girls. In the Danes it was shown that the sesamoid ossified on the average 12 ± 2.1 months before maximum stature growth in girls and 9 ± 1.4 months before in boys. Although the time of sesamoid ossification varied by as much as 4 years in boys and 3 years in girls, it was found that in both sexes ossification always preceded or coincided with the maximum velocity of stature at adolescence. This close association between the timing of peak stature velocity and sesamoid ossification was expressed by the correlation coefficients of 0.75 in boys and 0.57 in girls.

Therefore, the presence or absence of the adductor sesamoid has some importance in deciding the developmental status of the child. If the sesamoid is unossified then considerable growth in stature and facial dimensions can usually be expected. If the sesamoid shows initial ossification maximum puberal growth is usually imminent or already attained. If, on the other hand, the sesamoid shows considerable ossification, then maximum skeletal growth is probably taking place or passed and growth velocity can be expected to progressively decline. Naturally, observations on ossification of the sesamoid would be considered together with other information. Figure 2 shows the relationship between statural growth and sesamoid ossification in two boys enrolled in the University of Adelaide growth study.

Menarche.

Björk and Helm²⁵ showed that the age at menarche in Danish girls was closely associated with the onset of ossification in the adductor sesamoid of the thumb ($r=0.66$). On the average menarche occurred 17 ± 2.5 months after the peak velocity of stature. However, in some girls menarche occurred in the same year as the peak stature velocity. The onset of menarche can therefore be taken as an indication that the puberal growth spurt is well under way and in many girls it may even be passed. In this situation the clinician should not expect any significant skeletal growth in the future.

There is little association between eruption stages of the teeth and physical maturation although the association does increase during

puberty. In girls, for example, a correlation of $r=0.59$ has been recorded between the timings of second molar eruption and menarche.²⁴ Dental age is therefore less useful for skeletal age assessment than other physiological events such as peak stature velocity, ossification of the adductor sesamoid and menarche. Further investigation is required to ascertain if other events taking place during development have any predictive value in the analysis of general and craniofacial growth.

SUMMARY

Orthodontic treatment can be planned more objectively when the child's general developmental status and future growth potential is taken into account. This paper outlines several methods of analysis that are applicable in orthodontic practice. All procedures are within the scope of the average practitioner.

Post-eruptive dental maturity is estimated by reference to published standards of tooth eruption in Australian children. The pre-eruptive stages of tooth formation can be assessed from lateral jaw roentgenograms.

Serial measurements of stature or radial length provide observations of general growth events such as the **pre-puberal minimum** and **puberal maximum** growth velocities. The use of parent-specific charts add to the accuracy of stature analysis. Growth of the facial skeleton is closely associated in timing with general skeletal growth at adolescence.

Ossification of the adductor sesamoid in the thumb, detectable on hand and wrist roentgenograms, and, in girls, the onset of menarche have been shown to bear a close relation to the timing of the puberal growth spurt. In the absence of serial recordings of stature, these events are useful guides in determining the time of maximum skeletal growth.

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