CRANIO-FACIAL GROWTH AT ADOLESCENCE

The major part of head growth is completed early in the child's life. By four years, width is practically completed, and although growth in head length continues thereafter, it is at a greatly reduced rate. Head length, breadth and circumference are about 96% of adult values at approximately ten years. These dimensions, however, do have growth spurts during adolescence although the maximum increments are less than 2 mm per year. In an endeavour to better understand growth of the head and relative structures for orthodontic purposes, several accurate longitudinal studies wherein lateral radiographs were employed to record changes in the facial and cranial skeleton during adolescence, have been carried out. The findings of the investigators leave little doubt that an adolescent spurt occurs in most facial dimensions.

Tirk's 1948 lateral x-rays taken with the Broadbent-Bolton Cephalometer of 16 individuals in longitudinal study of the nasal, oral, total facial and cranial areas led him to conclude that an adolescent spurt of growth occurred in each of the areas studied. The cranial rate of growth slowed earlier than the more rapid rate of the facial areas which were longer
sustained.

It has been mentioned that three basic elements determine the general shape of the cranium: the brain case, cranial base, and facial skeleton, each with its own distinct growth pattern. **Cranial-Base Development** may significantly affect that of the other two elements. A change in shape of the cranial base during growth will vary the shape of the brain case\textsuperscript{12}. With respect to the facial skeleton the cranial base is significant because, as pointed out by Brodie 1953\textsuperscript{20} "the upper face is firmly attached to the anterior cranial base" (i.e. anterior to sella turcica), "through the medium of the sutures at the fronto-nasal area in front, at the zygoma laterally and posteriorly through the pterygoid buttresses" (p. 148). The mandible is influenced by the posterior part of the cranial case as the glenoid fossa is part of the temporal bone.

As a follow-up to his previous study, 1951\textsuperscript{11}, Bjork's 1955\textsuperscript{12} investigation using lateral head x-rays of 243 twelve-year-old Swedish boys (later studied at twenty years using the same method), was conducted to analyse the growth mechanism of the cranial base during adolescence. A conclusion drawn from the investigation was that "the cranial base is elongated ventrally by frontal apposition in the
glabella region without any appreciable longitudinal sutural increment of the anterior cranial fossa" (p. 222), and, "during the period of adolescence the relation between the nasion—sella line and the deepest median contour of the anterior cranial fossa remains noticeably constant, whereas tuberculum sellae and dorsum sellae appear to be raised in relation to the centre of sella". (p. 224)

Bjork found that generally the shape of the cranial base remains stable with age. However, 23 cases, i.e. approximately 10% of the material studied, showed flattening of the cranial base — the nasion—sella—basion angle increased by up to 5°. The anterior cranial fossa remained stable. In the middle cranial fossa the rotation has as its centre the sphenoorbital synchondrosis. A flattening of the cranial base is usually accompanied by a reduced height of the brain case (nasion to bregma) with sella to bregma increasing and sella to basion markedly reduced. The posterior and middle cranial fossa being therefore raised in relation to the anterior fossa. This rotation is co-ordinated with a rotation due to sutural growth of the lateral regions of the cranial base and the brain case, a change in shape of the cranial base varying the shape of the brain case. See figures 10, 11 and 12.
Bjork found that flattening of the cranial base leads to rearward and upward displacement of foramen magnum thereby increasing its angle and altering the balance of the head, resulting in upward tilting of the face giving an impression of greater facial prognathism than is actually the case and perhaps "recessive forehead".

Figure 10  Reference points on lateral head x-ray photographs within the cranial base and the brain case.

(From Bjork 1955)
Bjork (p. 200) defines the reference points on the cranial base and in the brain case thus:

- **Articulare (ar)** — Point at the junction of the contour of the external cranial base and the dorsal contour of the condylar process. (The mid-point is used at double contouring of the condyles).
- **Basion (ba)** — The perpendicular projection of the anterior border of foramen magnum (endobasion) on a tangent through the lower contour of the foramen.
- **Bregma (br)** — The junction of sagittal and coronal sutures on the surface of the vault.
- **Ethmoidale (eth)** — The lowest median point of the contour of the anterior cranial fossa, corresponding to the cribriform plate of the ethmoid bone.
- **Frontale (f)** — A point on the surface of the frontal bone defined by a line projected at right angles from the mid-point of a line connecting nasion and bregma.
- **Lambda (l)** — The junction of lambdoidal and sagittal sutures on the outer surface of the vault.
- **Nasion (n)** — The most anterior point of the nasofrontal suture.
- **Opisthocranion (op)** — The most posterior point in MSP on the outer surface of the vault, defined as the largest distance from nasion (excluding the external occipital protuberance).
- **Sella (s)** — The center of the bony crypt forming the sella turcica. The surface of the sella turcica is determined independently of the contours of the clinoid processes, and is limited upward by a line from tuberculum sellae to dorsum sellae. The center is defined as the mid-point of the greatest diameter from tuberculum sellae.
- **Sphenoidale (sphen)** — The uppermost point of tuberculum sellae in MSP.

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**Figure 11** The general growth pattern of the cranial base and the brain case from 12 to 20 years of age in the same individuals. The sample comprises 243 cases.

*(From Bjork 1955)*
Figure 12  The covariation between cranial base deflection and brain case rotation. The drawings are constructed from mean value calculations at the 20 years of age level, from cases with pronounced deflection compared with cases where the cranial base is flattened, each group comprising twenty-four cases (10 per cent of the sample).

(From Bjork 1955)

In another 10% of cases there was actually a closing of the nasion-sella-basion angle by up to 5.5° so that with the head in natural balance a more retrognathic impression is given and prominent forehead may be associated therewith.
Figure 13  X-ray tracings of two 20 year old individuals representing: (a) maximum and (b) minimum facial prognathy. The drawings are oriented with the nasion-sella line horizontal.

(From Bjork 1955)

Facial Change: In co-ordination with the rotation of the cranial base and the brain case there is also a rotation of the facial structure. With a cranial base rotation the temporal bone and hence the glenoid fossa will be displaced resulting in an alteration of the mandibular position. Bjork states that the direction of growth of the condyle will influence the general shape of the mandible. Upwards will increase vertical height and backwards will increase sagittal length. The gonial angle size will be influenced by the direction and amount of condylar growth as well as the amount of appositional growth at the gonial angle.
The Maxilla: The body of the maxilla increases in length toward the palatine bone and is lowered as a result of the growth which occurs between the palatine bone and the pterygoid processes. In the individual this lowering may be forward and down or backward and down. Such variation in the growth direction of the maxilla is in co-ordination with cranial base rotation and with sutural growth of the upper facial structure. Brodie's 1953 study led him to conclude that the basion-sella-nasion angle may vary, but where such occurred he was of the opinion that it was not correlated with behaviour of the facial mask as indicated by the chin point movement. Brodie had studied the tracings of all lateral head x-rays of 19 white males over the space of 8 to 17 years of age. The following is a summary of his findings concerning the behaviour of certain structures and landmarks during the abovementioned growth period.

The nasal floor tended to remain stable throughout growth. Where change did occur, the anterior nasal spine dropped more than the posterior nasal spine relative to the anterior cranial base.

Pterygo-maxillary fissure (PTM). In the anteroposterior direction this was the most stable point in the facial area. From its location at three years of age it dropped straight down during growth, as did the
posterior nasal spine.

The occlusal plane relative to sella-nasion in 50% of cases was stable. When alteration occurred, the posterior part was lowered more so than the anterior section, the change being more pronounced than any taking place in the palate. The lower border of the mandible in over 50% of cases showed no appreciable change. If such did occur the tendency was for it to become more parallel to the anterior cranial base.

According to Brodie the nasion-sella-gnathion angle in 11 of 19 cases remained quite stable. A backward swing of the face was manifested by the other 7 to an average of 2° with 4° maximum. The sella-nasion-gnathion angle (chin point behaviour) was in an anterior direction in 15 out of 19 cases ranging from 3° to 6° for the forward movement of gnathion. Four cases showed no movement.

Late stages of growth were accompanied by a continuation of the downward and forward movement of anterior nasal spine and pogonion. This was to a greater degree than occurred in the denture which became less prominent. Brodie found that the incisors did not necessarily become more upright. Porion point had a large range of variation of behaviour during the growth period - from a straight downward movement to a straight backward one. Such movement was not related
to opening or closing of the basion-sella-nasion angle
or behaviour of the chin point.

Lande's 1952 study of 34 series of head plates
of male subjects(a) is also significant among investiga-
tions by orthodontists into jaw-growth patterns. The
average individual age span of his sample was 4.4 to
17.1 years. A total of 509 plates were included with
an average of 15 to each series. Sella-nasion and
Frankfort horizontal planes were used for orienting
and superposing; with points nasion, anterior nasal
spine, subspinale, supramentale, pogonion, gnathion and
gonion being used in measuring growth changes. Initially
data for three age ranges were studied: 3-7 years;
7-12 years; and 12-18 years.

With regard to changes in profile, Lande's
findings for the three age ranges are illustrated in
figure 14. The mean diagram for 3-7 years shows no
significant changes on the profile in an antero-
posterior direction of the points A, B, or Gn. For
7-12 years; a significant forward movement of Gn
(1.3 mm) but no significant change for A or B. 12-18

(a) The 34 male subjects (none of whom had ortho-
doncic treatment) were a random sampling: 33 from
files of the Bolton study, Department of Anatomy,
Western Reserve University; and 1 from the
Department of Orthodontia, University of Illinois.
Figure 14  Mean Profile Changes. (From Lande 1952)

years:  Gn, 3.7 mm;  B, 2.2 mm;  and A, 1 mm. Changes in convexity were measured by the N - A - Gn angle for all three age ranges.

The average continuous change of gnathion in an antero-posterior direction on the profile from the beginning to the end of each series is diagrammatically represented in Figure 15. From his study Lande felt the following conclusions warranted:

1  That the mandible "tended to become more prognathic in relation to the brain case during growth but the maxilla showed very little change" (p. 89).

2  The increase in mandibular prognathism generally occurred after seven years.

3  A decrease in the inclination of the lower border
of the mandible (measured from the sella-nasion plane) was associated with the increased prognathism.

4 Alveolar bone growth did not keep pace with growth of the skeletal base in a horizontal direction (point B did not keep pace with gnathion).

5 The convexity of the face nearly always decreased — retrognathic cases did not become more retrognathic.

6 There was no correlation between the original facial type at 7 years of age and the growth change at gnathion occurring from 7 to 17 years. The majority of cases showed the same growth tendency regardless of type.

Using serial céphalometric roentgenograms of
fifteen persons, age range 4 to 20 years, Nanda's 1955 analysis of growth patterns of the human face indicated an adolescent spurt in most facial dimensions. He found that while there is a general circumpuberal rise, the time of the onset and that of the peak of the rate of growth are different for the various dimensions of the same child. Further, the face tends to have its circumpuberal maximum slightly later than that for the general body height, and that the body height growth is completed sooner than the facial growth. Nanda's survey also indicated that girls show relatively less facial growth during adolescence than boys.

Bambha 1961 studied the serial x-rays of 25 boys and 25 girls who were Denver-born of northern European ethnic origin. The age range of the study of these subjects from upper middle class families was from one month to 30 years. Between twelve and nineteen lateral head films were available from each individual. On each film the following eight measurements were taken from the centre of sella turcica to the periphery of the bony outline. Three cranial: 1, Sella-Bolton Pt (BP); 2, Lambda (La); 3, Bregma (Br); and facial: 4, Nasion (Na); 5, Subspinale (SS); 6, Infradentale (ID); 7, Gnathion (Gn); 8, Gonion (Go).

Although the age range was 1 month to 30 years, the main interest was centred on the adolescent growth
period relating facial and cranial growth to the growth in body height.

Bambha's findings in general support those of Nanda. There is an adolescent acceleration in facial growth which usually occurs a little after that in body height. Facial growth shows small increments after body height is completed; more so in boys than in girls. The total duration for accelerated facial growth is approximately the same as it is for accelerated height gain. In girls however, it is considerably less. Girls had smaller absolute measurements at a slower rate of growth and matured 2 to 3 years earlier than boys.

The cranium tended to follow the neural type of growth but a small adolescent spurt is shown occasionally. The skull base tends to follow a growth pattern in between the neural and skeletal types.

Bambha commented that SNa was usually satisfactory but in some subjects Na showed an upward shift producing a clockwise rotation of the tracing.

He also found in general agreement with Broadbent and Brodie that facial pattern once established essentially remains the same.

Bambha and Van Natta studied 22 boys and 28 girls longitudinally, using lateral plates at yearly intervals from 9 years 9 months to 17 years 9 months.
The subjects who were born in Denver of North European ancestry, were taking part in the longitudinal growth study at the Child Research Council. The purpose of this study was to relate the growth of the face during adolescence to a measure of skeletal development based on hand and wrist x-rays using the Greulich and Pyle Atlas.

The data on boys and girls was analysed separately due to the sex difference in developmental age. Three stages of skeletal maturation were used: 10, 12, and 14 years for girls, and 12, 14 and 16 years for boys. These encompassed the period during which all individuals in the study had their maximum adolescent growth spurt.

Sella–gnathion was designated the dimension on the head x-ray for measurement as it "has the maximum absolute amount of growth". See figure 16.

Findings: There was an association between skeletal maturation during adolescence at the two extremes—early and late maturers. Early maturers with advanced skeletal age have an early adolescent facial growth spurt while the children with retarded skeletal maturation tend to mature late. The large middle group of average maturers exhibited substantial variation. It was felt that there was sufficient individual variation to render the orthodontists'
Figure 16 The sella-gnathion (SE-GN) dimension measured on the lateral cephalometric roentgenogram to establish the time of maximum circumpuberal growth during adolescence.

(From Bambha and Van Natta 1963)

prediction on a specific patient imperfect.

Although Hunter 1966\cite{58} challenged the findings of Nanda and Bambha his conclusions as Krogman 1968\cite{67} says (p. 181), "differed more in degree" rather than in kind. Hunter himself stated that facial growth continued into the twenties in most males after body height growth was complete. In females facial growth was obviously earlier; and in the late teens both facial growth and body height were complete.

Tanner 1962\cite{107}, in dealing with growth of the head and face during adolescence, affirms (p. 16) that
the spurt is pronounced in the mandible which seems to lag behind the rest of the face in its development and then responds most during the adolescent period. The ramus has the largest spurt of the facial measurements — in boys up to 25% of the ramus height occurs after twelve years of age, while between 12 and 20 years, 6-7% of mature growth remains to be completed in the cranial base (sella turcica to nose root and sella turcica to mandibular joint). Accelerated growth in the mandibular corpus in antero-posterior length also takes place and in depth from the lower incisor to the point of the chin. Resulting from this accelerated mandibular growth the facial appearance is changed; the more so in boys than in girls with the jaw relatively longer, thicker and more prominent than previously.

In referring to the less-marked acceleration of maxillary antero-posterior growth, Tamer mentions the area directly above the incisors as accelerating slightly in forward motion. Bjork 1951 had found that both jaws are more prominent with facial changes towards maturity producing a straighter profile and more pointed chin; the incisors of both jaws becoming more upright (p. 198). Bjork noted that there may be, however, considerable individual variation from the average growth changes — additionally demonstrated by
Bjork and Palling 1955\textsuperscript{16} (p. 210).

The frontal bone was studied by Meredith 1959\textsuperscript{79} who specifically examined the nasion-bregma diameter of thirty American-born white girls of north-western European ancestry, during the age range from five to fifteen years. From this long term longitudinal study, Meredith found that the nasion-bregma diameter increases at a declining rate during childhood, but during adolescence there is an acceleration which occurs sometimes before, sometimes after, and sometimes coincidental with the circumpuberal growth spurt. There were wide individual differences in the amount of change during childhood and adolescence, with some girls having no detectable spurt. The nasion-bregma chord becomes slightly more variable as age advances. At 5 years of age the mean average of the group for the dimension was 10.19 cm; at 15 years of age it was 0.68 cm larger – an increase of 6.7%.

Nose Growth: There is an acceleration, particularly in the antero-posterior direction in most children. Subtelny's 1959\textsuperscript{106} longitudinal analysis using lateral plate x-rays shows that there is accelerated growth of the soft tissues as well as the basal bone of the nose in most boys bringing the point of the nose further forwards and downwards relative to the rest of the face (p. 506). The degree of change in nose dimension,
however, varies from one individual to another—a marked change in some with a hardly detectable change in others.

The pituitary fossa does not appear to have a spurt of growth in some children (Acheson and Archer 1959\(^2\) p. 59 and 61). While finding considerable individual variation, the last mentioned authors concluded that "... as a rule, rate of growth in depth but not length undergoes a significant increase during the same year as the child experiences its pre-adolescent growth spurt in stature" (ibid., p. 65).

**Brain Growth:** It is possible that brain enlargement occurs during adolescence, but this cannot be substantiated. Tanner 1962\(^{107}\) (p. 14) points out that the middle and posterior cranial fossae enlarge and the increase in height of the cranial vault above its base is of a degree not accounted for by bone and scalp growth. The cranial base posterior to sella turcica is apparently lowered (Zuckerman 1955\(^{117}\) p. 532), as well as increasing in length (Ford 1958\(^{36}\) p. 502). Presumably there is an associated growth of the temporal and parieto-occipital lobes of the brain or some deeper structures. Data on brain weight and dimension is cross-sectional and not fine enough to detect an acceleration if such occurs. Similarly data on the eyeball is only sufficient to "hint, perhaps at
a slight adolescent acceleration, but certainly not to establish it. Anatomical measurements suggest that any dimensional increase is in the sagittal length of the eye more than for the transverse or vertical diameters (Tanner 1962 p. 15).

The Pharynx: has an acceleration of growth in length with the hyoid bone descending from being level with the mandible before 'puberty' to considerably below it after (King 1952 p. 31). The antero-posterior diameter of the pharynx has a much less marked change.

Alteration in facial expression occurs in most boys to a noticeable degree and definitely so in some cases. Tanner 1962 illustrates this with serial photographs at stages in the developmental progress through adolescence of selected subjects. This is not attributed entirely to the relatively small skeletal changes and an apparently associated "subtler change in muscle size and subcutaneous tissue distribution" (p. 17), but is due also to the effect of hormones on the tissues of the face or even perhaps on the brain itself (is the suggested explanation). The possibility of a psychologically-based alteration in facial expression is discounted by Tanner 1962 (p. 18) for the reason that the change in expression coincides too closely with the beginning of the spurt in genital growth whether this be early or late. But the possibility of
a psychological basis, is still not ruled out because of the coincidence mentioned by Tamer.

As a final statement on the growth behaviour of the cranio-facial skeleton during adolescence there follow some conclusions, arrived at from the studies referred to, as being of import to the orthodontist.

1. The cranial base area has considerable influence upon total facial prognathism and the antero-posterior relationship of the jaws.

2. The cranial base generally remains stable; if variation does occur, it is posterior to sella turcica. The anterior cranial fossa is unchanged. Forward growth of the forehead during adolescence is fully accounted for by development of the brow ridges and the frontal sinuses.

3. Most facial dimensions have an acceleration in growth, the maximum velocity of which is usually reached a few months after that of the statureal height acceleration. The duration of the spurt in facial growth is approximately the same as that of body height, and so facial growth continues after height growth is completed.

4. In boys the spurt in facial growth is more pronounced and sustained over a longer period than the less marked facial growth spurt in girls, which occurs chronologically earlier consistent with the
females' generally more advanced development to maturity.

5. The mandible, especially in boys, has the greatest acceleration of growth with the ramus showing the largest of the facial skeletal changes.

6. An acceleration in antero-posterior length occurs in the maxilla though to a much lesser degree than in the lower jaw.

7. As a result of 5 and 6, the profile, towards maturity, is in most cases straighter with a more pointed chin.

The Significance of Growth to Orthodontic Treatment Progress:

The effect of growth on orthodontic treatment is well acknowledged. Hellman 1937\textsuperscript{55} has submitted case histories of orthodontically treated and untreated children which led him to conclude (p. 782) "... that while mechanics furnishes the means by which the possibilities of orthodontic practices are realised, biology reveals a boundary of limitations within which our practices must be confined."

Nanda 1955\textsuperscript{90}, from his analyses of facial growth patterns at adolescence, decided (p. 673), "the orthodontist who constantly works with mechanisms underlying the growth of the face needs to adapt his methods of treatment to fit with and take advantage of these basic growth patterns".
The pertinence of the adolescent growth spurt to orthodontic treatment is recognised in the writings of Burstone 1963\textsuperscript{23}, Bjork 1955\textsuperscript{12}, Krogman 1958\textsuperscript{66}, Graber Chung and Aoba 1967\textsuperscript{48} et. al.

"It becomes apparent that successful results depend upon thorough treatment and the degree to which treatment is complemented by growth processes" (Buchner 1967\textsuperscript{22} on p. 60).
SECTION 3  ADOLESCENT GROWTH AND TIMING OF
ORTHODONTIC TREATMENT

In the light of what is known of growth and
development, it is clear that the adolescent growth
spurt is very pertinent to the treatment planning of
malocclusions wherein a maxillo-mandibular malrelation-
ship pertains — (the teeth largely reflecting the
basal antero-posterior jaw relationship).

The facial skeletal growth pattern associated with
the adolescent period is significant for the relative
increase in the dimension of the mandibular ramus.
Briefly, jaw growth at adolescence can aid orthodontic
treatment of Class II malocclusions and oppose that of
Class III. Such a statement while over-simplifying the
situation is broadly applicable. Certainly there is no
universal boundary or pattern, for as Buchner 196722
(page 60) states, "... there is only a wide variety of
patterns belonging to individuals".

The rapid growth of adolescence is of particular
significance where orthopaedic type treatment is called
for to redirect growth forces in order to reduce an
existing maxillo-mandibular malrelationship in the
antero-posterior plane. Where such a malrelationship
of the jaws is present the primary consideration in
treatment is to reduce or eliminate if possible the
basal discrepancy. The establishment of correct tooth relationships is secondary to and largely dependent on the success of the primary aim - certainly for stability of result. (Graber, Chung and Aoba 1967\textsuperscript{48} p. 1150.)

**Treatment of Class II Division 1 Malocclusion**

The possible combinations of maxillo-mandibular dento-skeletal relationships in the Class II category of malocclusion have been summarised by Krogman 1968\textsuperscript{69} (page 379). Coben 1966\textsuperscript{26} (page 5) states, "considering the wide variation in faces that exhibit the Class II malocclusion one might logically assume that treatment should also be varied".

While a skeletal malrelationship underlying a Class II division 1 malocclusion may range from maxillary protrusion, at one end of the scale, to mandibular retrusion at the other, with combinations of degrees of both in between, maxillary protrusion has been found to be less marked than mandibular retrusion (Krogman 1968\textsuperscript{69}, p. 379). Maturational retardation appears to be a factor associated therewith. (ibid., p. 380)

With a small or retrusive mandible the profile is convex. The anterior middle face height being long relative to the short ramus of the immature mandible, the gonial angle of which tends to be obtuse and the plane of the lower border rather steep.
Johnston (1965) suggests the patient with a small or retrusive mandible and retarded skeletal age may benefit from watching for a balancing-out of the skeletal pattern as the adolescent spurt is entered.

In severe Class II cases treatment should be initiated in the mixed dentition. Graber 1955 (page 495) and Graber et. al., 1967 (page 1165), when describing the application of intermittent extra-oral force, advocate early treatment for severe cases, but stress that treatment is most advantageous during the 'puberal' growth spurt. The orthopaedic type extra-oral force applied to the upper dental arch opposes forward maxillary growth while the mandible achieves its fullest potential.

The timing of treatment with the period of greatest growth is obviously pertinent. In the average girl treatment may be initiated chronologically earlier than in the average boy. Although beginning later in the boy, the acceleration in mandibular growth is greater and of longer duration. In theory, growth assistance to treatment is of a greater degree and over a longer period for the male patient at adolescence.

**Class II Division 2**

While in many cases of Class II division 1 malocclusion, a well-formed mandibular arch may permit orthodontic treatment being confined to the maxillary
arch, in the Class II division 2 malocclusion there is usually manifested a deep overbite often associated with crowding of the lower anterior teeth.

This malocclusion typically reflects a skeletal pattern of short lower anterior face height with a long vertical mandibular ramus, square gonial angle and associated "pronounced forward rotation" (Bjork 1969, p. 598) of the mandible.

In such cases orthodontic treatment should be commenced in the mixed dentition. Even prior to the application of extra-oral force to the upper first permanent molars, a Hawley bite plate and/or a lower fixed lingual expansion arch appropriately activated, is a recommended method of treatment aimed at reducing the deep bite, freeing the contained lower dental arch, and eliminating early the lower anterior crowding before tissues consolidate around the malposed teeth. With the application of extra-oral force to oppose forward growth of the maxilla, Class I relationships are attainable as the released mandible achieves its forward growth potential.

**Class III Malocclusion**

Korkhaus 1957 (page 889) states, "... the disturbances in the development of the upper jaw and middle face are just as reliable a characteristic of true progenia as the excessive growth and alteration
in the shape of the mandible". Certainly it seems that the underlying skeletal pattern in Class III malocclusions is revealed in cephalometric x-rays more often as maxillary sagittal deficiency rather than true mandibular prognathism. In such cases, orthodontic treatment involves some expansion of the maxillary arch. If Class I relationships are established before the onset of adolescence, retention should be continued throughout this period, during which the mandible usually accelerates in growth. Typically there is a minimum of anterior overbite in the treated case and during the growth spurt a strong tendency for this to diminish to an edge-to-edge relationship, or even anterior open bite, is to be expected.

In those Class III cases where treatment has required the head-chin-cap appliance to reduce the basal skeletal discrepancy, Graber et. al. (1967)\(^48\) advocate the duration and intensity of such therapy being increased during the time of greatest growth. Aimed at redirecting the powerful horizontal mandibular growth component to a more vertical one, this orthopaedic type treatment should be continued right up till the end of the adolescent growth spurt, especially in boys. (Burstone 1963\(^23\), p. 911, Graber et. al. 1967\(^48\), p. 1153.) In the latter this may mean till after eighteen years of age; while in some girls treatment
may not be necessary after approximately thirteen years. The maturational rate of the individual concerned is the factor governing the required duration of his or her treatment.

Orthodontically Unfavourable Growth Patterns

In dealing with the significance of timing orthodontic treatment to benefit from, or best cope with, jaw growth during adolescence, the usual types of Class II and Class III skeletal malrelationships met with, have been referred to. However, as stated by Moore 1969\textsuperscript{81} (p. 80), "... recognition of individual variability is a must in all orthodontic procedures". There occur, albeit infrequently, the extreme cases. The extremes of mandibular morphology described by Bjork 1969\textsuperscript{13}, are illustrative. Problems associated with treating "high angle faces" and "low angle faces" (Creekmore 1967\textsuperscript{27} p. 296) are described by the last mentioned author, as well as having received the attention of Graber et. al. 1967\textsuperscript{48}, Schudy 1968\textsuperscript{98}, Moore 1969\textsuperscript{81} and Bjork 1969\textsuperscript{13}.

Bases of Treatment Planning

It has long been acknowledged that in the treatment planning of cases of maxillo-mandibular malrelationship, the primary essential is to establish whether the difference in prognathism is increasing or decreasing during growth. (Bjork 1951\textsuperscript{11}, p. 202)
The importance of being able to assess the individual patient's developmental status is also clearly evident if treatment planning and execution are to be of a high order (Burstone 1963\textsuperscript{23} p. 911). Specifically, whether the child is approaching puberty, or if this period of rapid growth has already started. The timing of appropriate treatment with the period of greatest growth is essential to the achievement of the best possible treatment result. (Graber et. al., 1967\textsuperscript{48}, p. 1165.)

A convenient means of predicting and/or detecting the onset of the circumpuberal growth spurt is therefore a desirable adjunct to the orthodontist's "armamentaria".
SECTION 4  ASSESSMENT OF DEVELOPMENTAL AGE

In the orthodontic treatment planning of malocclusion involving a maxillo-mandibular basal malrelationship in the antero-posterior plane, it is clear that the adolescent growth spurt warrants adequate consideration.

The ability to ascertain just how far along the developmental road to physical maturity an individual has progressed, is significant if the best possible treatment result is to be attained. The commencement of the adolescent spurt of growth is the milestone in point.

Chronological Age is unreliable as an indication of developmental age, for the individual grows and develops according to his own largely genetically-determined 52, 91, 97, 107 time schedule which is quite independent of the calendar.

"Children do not all grow at the same time, nor do they grow at the same rates over the years. There are 'slow growers', there are 'fast growers', and there are those in between. Further there are times in the growth of all children of accelerated and decelerated rates. Finally, there are 'late maturers', early maturers' and those in between. ... The real age for growth timing is biologic and not chronological."
Biologic or Organic Age registers the rate of progress to physical maturity. Krogman 196867 sets out several sub-categories of this including chronological age, skeletal age, dental calcification and eruption, circum-puberal and morphological age. He states (p. 176), "certain it is that there is a basic inter-related pattern in the physical growth of the body. There is a grouped orderliness that is system-and-time linked."

This is well illustrated in Scammon's (1930) Systemic Growth Curves of the Human Child referred to previously (see Figure 2, p. 13, Section 1).

The orthodontist, in endeavouring to assess the developmental status of a subject, has some clinical guides of varying reliability.

Morphologic Age: As a measure of maturity has limited usefulness. A child who is above average height for his age may be developmentally advanced, or he may be merely a tall child, who on maturity, will be a tall man. Obviously, morphology is not a reliable indicator as it confounds maturity with size.

Tanner 1962107 (p. 74) suggests the concept of 'shape age' as being "more subtle and rewarding" than size, but acknowledges the difficulty in measuring change in shape. He refers to Medawar's (1944) diagram (see Figure 3, p. 16, Section 1) commenting
on page 75, "An equation can be found expressing the change of relations of the horizontal lines with the passage of time, and from this a shape age based on these relations could be developed".

Morphology, however, is only a small facet considered in assessment for growth prediction. Height-weight-age tables are not a precise yardstick for assessing the developmental age or status (of individuals) for people in most populations are heterogeneous (Greulich and Pyle 195952 p. 1). Additional to the genetic diversity of different racial types and mixtures of ethnic groups, there are significant differences in nutritional levels. On adding early-maturing and late-maturing strains to the above we have many factors which result in wide differences in age at the onset of adolescence and consequently the age at which the maximum annual increment in height occurs. Obviously there is a need for a reliable indicator of physiological status. SKELETAL AGE is by far the most commonly used method of assessing14, 23, 52, 67, 107, et al. physiological age. It is a measure of how far along the path of development to maturity the bones are as evidenced radiographically. The hand-wrist x-ray appears to provide a dependable 'yardstick' of the child's developmental progress. Greulich and Pyle 195952 on page 15, state:
"One gets the impression that at least in health the development of the child proceeds harmoniously in all of its parts. To the extent that it shows detectable evidences of progressive maturation, any organ system could, presumably be used for determining the developmental status of the organism as a whole." The skeleton, however, especially that of the hand and wrist, has the following advantages for this purpose: "The changes associated with progressive maturity are readily visible in the x-ray film; they occur in an orderly sequence; they cover the entire period from birth to early adulthood; they permit the direct comparison of children without regard to genetic or other differences in bodily size..." (ibid. p. 18.)

The sequence of development in each bone is the same in all individuals, whether the bone be advanced or retarded in respect to chronological age. Tanner 1962\(^{107}\) (p. 56) states: "Each bone begins as a primary centre of ossification, passes through the stage of enlargement and shaping of the ossified area, acquires, perhaps, one or more epiphyses and finally reaches adult form with epiphysseal fusion." The scheme of events in skeletal development occurs in a regular, definite and irreversible order, regardless of race (Tanner 1962\(^{107}\) p. 61; Greulich and Pyle 1959\(^{52}\) p. 42) or type; with only a minor sex difference which may
occur in the sequence of appearance of the centres of ossification in the hand-wrist x-ray. Where area of a centre was formerly used as an indication of maturity, shape change is now the criterion because of the factor of different sizes of individuals (Tanner 1962\textsuperscript{107} p. 57).

The maturative changes in the skeleton are intimately related to those of the reproductive system\textsuperscript{52, 107} which in turn are responsible for most of the externally discernible changes on which the estimation\textsuperscript{(a)} of general bodily maturity is usually based.

Greulich and Pyle 1959\textsuperscript{52} clearly demonstrate that the developmental status of the skeletal system parallels that of the reproductive system. A case of precocious puberty in a girl is described wherein the manifestations of early developing sex characters coincide with rapid skeletal development as revealed in periodic hand-wrist x-ray films. The child was noticeably tall compared with normal girls of her age, when the precocious developmental changes were manifested, and growth continued at an abnormally rapid rate to its completion (p. 8).

In such children, however, growth ceases very early and they are ultimately very short as adults. This is consistent with the known relationship between certain

\begin{itemize}
\item \textsuperscript{(a)} Tanner 1962\textsuperscript{107} p. 31 and p. 55.
\end{itemize}
sex hormones and growth - especially growth in the long bones, which is largely responsible for the increase in stature. Growth studies have shown conclusively that growth of the long bones begins to decelerate at about the time of puberty and that it terminates soon after. Greulich and Pyle's affirmation of this is endorsed by Tanner's 1962\textsuperscript{107} conclusion that the circumpuberal acceleration is due more to the increase in trunk length than the lengthening of the leg (p. 12). In the case of the girl with precocious puberty the hand-wrist x-ray showed epiphyseal fusion had already begun in the distal phalanges of the thumb and of the third finger, when she was examined at 5 years and two months, and this stage of skeletal development usually occurred between 13 and 13\frac{1}{2} years in normal girls of Greulich and Pyle's research series. The child's growth stature had ceased by the time she was ten years old and her height 4' 8".

"In precocious puberty the gonadal and related hormones are present abnormally early in quantities sufficient to cause the epiphyses of the various long bones to fuse before growth has continued long enough to permit the attainment of full normal adult stature." (Greulich and Pyle 1959\textsuperscript{52} p. 8)

The relationship of the skeletal systems developmental status to that of the reproductive is also
evidenced in the hypogenital states. Hypogonadal males, and females with comparable gonadal inadequacies, show growth, especially that of both upper and lower extremities, continuing for an abnormally long period of time. The hypogonadal subject having abnormally long limbs with short trunk. Evidenced in the hand-wrist x-ray film of the individual, will be the degree of skeletal retardation present; and whether the subject will further increase in stature or not may be deduced therefrom. In cases of this type, the film is also a check on the "effectiveness of endocrine or other therapy designed to palliate the condition" (ibid. p. 9).

The hypogonadal subject, having incomplete maturation of the reproductive system and a corresponding retardation of the skeletal system, is in contrast with the precocious-puberty-case, where there was an accompanying accelerated skeletal development; but at the same time close correspondence between the reproductive and skeletal systems in developmental progress is indicated.

The paralleling in developmental progress of the two systems also pertains in children who are normal and free from the aforementioned defects. As further evidence for their assertion, Greulich and Pyle relate the menarche in normal girls and the circumpuberal acceleration in stature. For the majority of girls in
their Research Series, "the maximum increment in height occurred during the year preceding that in which the menarche took place" (p. 9). This is in agreement with Deming 1957 who found (p. 112) menarche occurred "without exception" after the apex of the height spurt had been passed, and the findings of Bjork and Helm 1967 (p. 141). Figure 17 is Greulich and Pyle's illustration of their findings.

**Figure 17**  The numbers on the abscissa to the left of the vertical line indicate years before the menarche; those to the right, years after the menarche. (From Greulich and Pyle 1959)
Greulich and Pyle 1959\textsuperscript{52} on page 11 state: "It is evident from this and other similar observations that, by the time the maturation of the ovaries and of the other reproductive organs has attained a level at which menstruation is possible, the rate of growth in stature has already begun to decelerate. This deceleration is due principally to changes in the long bones of the lower limbs which precede, usually by only a short period of time, the obliteration of their epiphyseal cartilages, the fusion of the epiphyses with their shafts, and the consequent cessation of their growth in length."

The last mentioned authors maintain that for most normal girls a reliable prediction of menarche is possible from assessment of a hand-wrist x-ray taken during the pre-puberal period. See Figure 18.

Sex difference: Because of the acknowledged general precocity\textsuperscript{(a)} of girls' physical growth and development when compared with boys of the same chronological age, two separate skeletal standards were established by Greulich and Pyle in their Atlas.

The relative precocity of the skeletal development of girls is already apparent at 3 months of age and it

\textsuperscript{(a)} Tanner 1962\textsuperscript{107} points out (p. 63) that Pryor (1905, 1923, 1925) was the first to discover this.
Figure 18 "The mean skeletal age of each of three groups of girls from our Research Series whose relative skeletal status even in early childhood indicated quite accurately the order in which they subsequently attained puberty."

(From Greulich and Pyle 1959)

becomes more pronounced as they grow older. The skeletal status of the 13½ year-old girls in the Research Series of Greulich and Pyle (1959) was not equalled by the boys of the same group until they were 15½ years of age.

Girls are more mature at birth, before birth, and throughout the whole period of post-natal growth. Tanner 1962107 (pages 63-4) states: "It has been recently shown that this sex difference depends on
genes on the Y chromosome retarding skeletal development in the male. (Tanner, Prader, Habich and Ferguson-Smith, 1959.) There are a number of individuals of chromosomal formula XXY (who exhibit the symptoms of Klinefelter's syndrome) and others of formula XO (who suffer from Turner's syndrome). The skeletal age of the XXY corresponds closely throughout the whole period of growth with the XY normal male, and that of the XO, at least up to puberty, corresponds approximately with that of the normal female XX. Hence the conclusion above." Tanner comments that the mechanism of this genetic control is obscure.

However, as has been stated previously, regardless of sex, race, nutritional state, or be the individual early, average or late maturer, the order of ossification remains the same. The skeleton is advanced or retarded as a whole and skeletal ages obtained from different areas, e.g. hand and knee agree fairly closely (Tanner 1962^{107} p. 64).

Correspondence between the right and left hand in skeletal development is so close that "any divergencies in the overall skeletal maturation of the two hands are so minor as to be negligible in the evaluation of skeletal status from roentgenograms" (Greulich and Pyle 1959^{52} p. 29).
Greulich and Pyle include a radiograph of an incomplete hand and wrist of the mummy of a young girl excavated by archeologists near Thebes. The child was estimated to have lived more than 3,000 years ago. The features visible in the x-ray suggest that the carpals ossified in the same order thousands of years ago as they do today.

On page 186 of the Greulich and Pyle 'Atlas' are listed the 'Maturity Indicators' in the order that ossification begins in the individual bones and epiphyses of the hand and wrist. These are depicted in the accompanying x-ray plate. See Figure 19.

It is noted that the adductor sesamoid is not prone to irregularity in its order of appearance as a maturity indicator. Referring to Greulich and Pyle's standards, one finds the sesamoid is first radiographically evident in the female standard 19 (skeletal age 11 years) on page 162, while the standard 23 (skeletal age 13 years) page 106, is the first male standard to evidence its ossification.

The samples (a) in Konie's 1964 study were found to agree closely to the standards of Greulich and Pyle.

(a) 152 males age range 7 years 9 months to 24 years, and 162 females from 7 years 6 months to 22 years, residing in the Chicago area. The subjects were examined with hand-wrist x-rays and mid-sagittal head laminagrams.
Figure 19  The individual carpals and epiphyses in the numbered hand opposite are numbered approximately in the order in which their ossification begins: (From Greulich and Pyle 1959)

1  capitate
2  hamate
3  distal epiphysis of the radius
4* epiphysis of proximal phalanx of the third digit
5* epiphysis of proximal phalanx of the second digit
6* epiphysis of proximal phalanx of the fourth digit
7  epiphysis of the second metacarpal
8  epiphysis of distal phalanx of the first digit
9  epiphysis of the third metacarpal
10 epiphysis of the fourth metacarpal
11 epiphysis of proximal phalanx of the fifth digit
12 epiphysis of middle phalanx of the third digit
13 epiphysis of middle phalanx of the fourth digit
14 epiphysis of the fifth metacarpal
15 epiphysis of middle phalanx of the second digit
16 triquetral
17 epiphysis of distal phalanx of the third digit
18 epiphysis of distal phalanx of the fourth digit
19 epiphysis of the first metacarpal
20* epiphysis of proximal phalanx of the first digit
21 epiphysis of distal phalanx of the fifth digit
22 epiphysis of distal phalanx of the second digit
23* epiphysis of middle phalanx of the fifth digit
24* lunate
25* trapezium
26* trapezoid
27* scaphoid
28 distal epiphysis of the ulna
29 pisiform
30 sesamoid of adductor pollicis (the sesamoid of flexor pollicis brevis is visible through the head of the first metacarpal, just below the numeral 2 on the epiphysis of the proximal phalanx of the thumb).

* Irregularities in the order of appearance are most apt to occur in those centres indicated by asterisks.
The former's investigation was to determine whether there was correlation between the closure of the sphenoccipital synchondrosis and the maturation of the hand and wrist. In concluding that a correlation did exist, Konie found (p. 312) that: in the female the sphenoccipital junction showed a consistency in initial fusion at the skeletal age of 10\(\frac{1}{2}\) years (± 6 months) with complete closure in all cases except one, at the skeletal age of 13\(\frac{1}{2}\) years. In boys, the majority of cases showed initial fusion occurring at 12\(\frac{1}{2}\) years skeletal age (Greulich and Pyle standards) which corresponds to the 10\(\frac{1}{2}\) year female standard. Complete closure of the sphen-occipital synchondrosis in the male was by the skeletal age of 16 years - which corresponds to the 13\(\frac{1}{2}\) years skeletal age standard of the female. Konie's findings substantiate the sex difference that the female is ahead in the rate of skeletal maturation. Complete obliteration of the junction in the males required a slightly greater length of time after initial ossification than it did in the females (Konie 1964\(^6\) p. 312).

Konie noted that the sesamoid (according to Greulich and Pyle's standards in the hand-wrist x-ray) was due to appear during the six-month period following the commencement of fusion of the sphen-occipital junction evidenced in the laminagrams.
Acceleration or retardation of skeletal development, as indicated by comparing hand-wrist skeletal age with chronological age, showed corresponding alterations in maturation of the cranial base at the sphenoo-occipital synchondrosis. This applied not only with Konie's general sample but also with patients (a) of known endocrine disturbance included in his study.

The standards of Greulich and Pyle's Atlas are not expected to fit exactly any group of children. As has been previously mentioned, because of genetic differences, children grow and develop at different rates even when adequately nourished and not handicapped by serious illness. Furthermore, most populations are heterogeneous with wide diversity of types of individuals. Considering too, the marked differences in nutritional levels and the early and late maturers, the Greulich and Pyle standards are precluded from fitting exactly any group of children. Nevertheless, the standards do provide a means of reference for an individual or a group.

The maturity indicators, however, are universal in application. The fact that they "tend to recur regularly and in a definite and irreversible order",

(a) Two hypopituitary males, one hypopituitary female and one hyperpituitary female added to the sample to study extreme variation.
marking the skeletal progress of the individual towards maturity, means that the hand-wrist x-ray is a reliable indicator of the individual's developmental status.

In the introduction, reference was made to the study of Bjork and Helm 1967\(^1\). At this juncture it is pertinent to quote again from their findings regarding the ulnar sesamoid of the adductor pollicis, which is the maturity indicator designated 'Number 30' in the individual bones and epiphyses of the hand and wrist, as shown in Figure 19. From their longitudinal study, Bjork and Helm found there was a close association between the age at maximum growth in body height and the age when ossification of the ulnar sesamoid at the metacarpophalangeal joint of the thumb occurred.

"... The sesamoid was ossified on an average 12 ± 2.1 months before maximum puberal growth for the girls and 9 ± 1.4 months before, for the boys." (p. 136.)

Individually, in both sexes, it was found that the onset of ossification of the ulnar sesamoid either preceded or coincided with maximum puberal growth. It did not take place after the circumpuberal growth spurt and usually occurred one year before. "Onset of ossification of the sesamoids therefore indicated that maximum puberal skeletal growth was imminent or attained." (p. 136.)
Bjork and Helm 1967\textsuperscript{14} (p. 140) point out that detection of maximum "puberal" skeletal growth is most easily determined by periodic measurement of height and recommend this as routine procedure in orthodontic cases treated over a long period. Radiologic examination of the ossification of the adductor sesamoid of the thumb is an added guide especially in cases where the longitudinal records of height increments are not available. As a dental film adequately covers the area of the first metacarpophalangeal joint of the thumb, the radiologic procedure is considerably facilitated.

\textbf{Individual Variations in the Rate of Skeletal Maturation:} A method of measuring, and for expressing, the average maturational velocity of a growing child during a specified chronological period has been developed by Tanner, Whitehouse and Healey.\textsuperscript{(a)}

The term "Velocity", when applied to skeletal development, may be considered as expressing the amount of developmental progress towards maturity of the skeleton for a given unit of time. Marshall 1969\textsuperscript{76} refers to the method of Tanner et. al. - the "TW" method - in which a number of points is allotted to each of the twenty bones in the hand and wrist according

\textsuperscript{(a)} Tanner, J.M., Whitehouse, R.H., and Healey, M.J.R. (1962) referred to by Marshall 1969\textsuperscript{76} (p. 91)
to the progress that bone has made towards its mature state. The unit of "distance" then is the "point"; and the measure of velocity of skeletal maturation is "points per year". A child's developmental velocity is determined by allotting a score to each of two radiographs which are separated by an interval of time in their taking e.g. one year.

The difference between the scores is divided by the time interval ("in years or decimals of years"), to express the velocity of maturation at so many points for the year. Marshall mentions that the "TW" method has been applied to children taking part in the London Longitudinal Growth Study. In a year of chronological age the growth velocity of an individual may be compared to the average for his or her peers. (See tables 3 and 4.) "It will be possible to evaluate the Tanner and Whitehouse method fully only when its application to large numbers of subjects in longitudinal studies has shown how accurately it measures their progress towards maturity." 76

DENTAL AGE

Teeth of both the deciduous and permanent dentitions erupt in a characteristic sequence. Although there is a wide range of variability with regard to ages at eruption, any advancement or retardation is usually constant throughout the dentition. The view of Nelson
Table 3  BOYS

<table>
<thead>
<tr>
<th>Age (yrs)</th>
<th>No. of subjects</th>
<th>Mean rate (points/yr*)</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0 - 6.0</td>
<td>54</td>
<td>41.0</td>
<td>17.5</td>
</tr>
<tr>
<td>6.0 - 7.0</td>
<td>62</td>
<td>50.5</td>
<td>22.4</td>
</tr>
<tr>
<td>7.0 - 8.0</td>
<td>59</td>
<td>49.9</td>
<td>21.6</td>
</tr>
<tr>
<td>8.0 - 9.0</td>
<td>49</td>
<td>39.9</td>
<td>18.1</td>
</tr>
<tr>
<td>9.0 - 10.0</td>
<td>39</td>
<td>43.4</td>
<td>24.7</td>
</tr>
<tr>
<td>10.0 - 11.0</td>
<td>39</td>
<td>57.7</td>
<td>33.2</td>
</tr>
</tbody>
</table>

*Calculated by dividing increase in number of points by exact time interval between two successive x-rays of each child.

Table 4  GIRLS

<table>
<thead>
<tr>
<th>Age (yrs)</th>
<th>No. of subjects</th>
<th>Mean rate (points/yr*)</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0 - 6.0</td>
<td>54</td>
<td>45.7</td>
<td>18.3</td>
</tr>
<tr>
<td>6.0 - 7.0</td>
<td>57</td>
<td>48.0</td>
<td>20.1</td>
</tr>
<tr>
<td>7.0 - 8.0</td>
<td>55</td>
<td>46.2</td>
<td>21.2</td>
</tr>
<tr>
<td>8.0 - 9.0</td>
<td>51</td>
<td>53.0</td>
<td>27.5</td>
</tr>
<tr>
<td>9.0 - 10.0</td>
<td>41</td>
<td>70.8</td>
<td>41.6</td>
</tr>
<tr>
<td>10.0 - 11.0</td>
<td>23</td>
<td>101.3</td>
<td>68.6</td>
</tr>
</tbody>
</table>

*Calculated by dividing increase in number of points by exact time interval between two successive x-rays of each child.

Tables 3 and 4 show the means and standard deviations of the velocity of skeletal maturation of boys and girls respectively.

(From Marshall 1969)

(a) Referring to the above tables, one notes the marked increase in the mean rate of points/year for girls (table 4) in the 10-11 yrs of age group — (101.3 points). This could be interpreted as reflecting the adolescent growth spurt which some of the twenty-three girls would be commencing. Although the largest rate increase for boys (table 3) is also at the 10-11 yrs of age group the degree of increase is, not unexpectedly, much less marked than that for the girls.
1959\textsuperscript{92} (p. 21) that if the first tooth erupts early so will subsequent eruptions be early, is found to be true in the experience of the author.

The general developmental precocity of the female, while not holding for the deciduous dentition, is marked in the permanent dentition with each tooth erupting earlier in girls, than in boys by an amount varying from one tooth to another (Tanner 1962\textsuperscript{107}, p. 68).

The cross-sectional survey of Gates 1963\textsuperscript{43} concerning permanent tooth eruption in New South Wales children indicated "all teeth in the females showed earlier eruption than corresponding teeth in the males. The smallest difference was between the lower first molars, 0.126 years, while the largest was 1.093 years between the lower canines." (p. 61.)

Tanner 1962\textsuperscript{107} (p. 70) states: "... while girls are ahead of boys in what we may call general dental age, they are considerably more ahead for some teeth than others. Particularly is this so of the canines, which are so advanced in girls that the lower one usually appears before the upper first premolar, a sequence which is rare in boys (Hurme 1949, Adler and Godeny 1952, Clements, Davies-Thomas and Pickett 1953b)."

Girls are advanced not only in eruption but "throughout all permanent tooth development from the
earliest stages of formation, that is from birth onwards. (Tanner 1962 p. 72.) Dental maturity age of boys is about 0.96 that of girls of the same chronological age whether calculated by eruption or calcification data (Gleiser and Hunt 1955; Garn, Lewis, Koski and Polacheck 1958 (p. 566)). This is a markedly smaller sex difference than the equivalent ratio for skeletal age (about 0.80). 

**Dental Development and Maturational Status**

Various investigations have been undertaken to establish whether a relationship exists between the formation and/or eruption of a specific tooth or teeth and the maturational status of the individual.

Meredith 1959 examined a possible relationship between odontiasis and the circumpuberal growth spurt. In his longitudinal study, the mandibular permanent canine was a particular focus of interest because "the typical boy lags in relation to the typical girl more with respect to eruption of these teeth than with respect to eruption of any other teeth". It being acknowledged that on average the typical girl reaches the circum-adolescent growth spurt approximately two years ahead of the typical boy, Meredith primarily sought to examine a hypothesized common factor underlying "these systematic osseous and odontic sex relations". Supplementing the central problem was a
study concerning the relationships between the eruption of the mandibular permanent first and second molar teeth and the adolescent growth spurt.

The subjects in the study were 43 girls and 29 boys predominantly American born white children of north western European ancestry, above-average in socio-economic status, living within the vicinity of Iowa City. The likelihood of continued residence and willingness to cooperate were conditions of a child's inclusion in the study, which commenced on each subject at five years of age and continued with an examination every six months up until after the adolescent acceleration in stature.

Every semi-annual examination for each individual consisted of: (1) measurement of stature; and (2) alginate impressions of the mandibular arch to provide plaster casts.

Each stature record was the average of two independent determinations or four determinations when the two differed by more than two millimetres. Estimation of the age at which the crest of the acceleration in stature occurred was by plotting the semi-annual accretions recorded, to provide the basis for drawing an absolute increment curve by the graphical method; "the age corresponding with the maximum of the circum-puberal hump in the curve was recorded". Estimates
were made to the nearest month. Eruption age of the canine teeth was to the nearest month for the left tooth and the right tooth and determined "by seriatim inspection of the casts for each subject" by two independent observers. The same examination procedure was employed for the mandibular permanent first and second molar teeth.

Meredith concluded from his investigation that the age of the circum-adolescent acceleration in stature and age of eruption of the mandibular permanent first and second molar teeth varied independently. With regard to the eruption of the mandibular permanent canine and the age of the adolescent statural acceleration there was no more than a slight co-variation.

Lewis and Garn 1960 found that the teeth are not unusually accelerated or retarded in their development when growth is faster or slower. They observed however, "it is evident from clinical studies that tooth eruption is accelerated in early-maturing girls..." (p. 76).

Gron's 1962 study of permanent tooth emergence was conducted on 434 male and 440 female healthy, white Bostonian children of lower socio-economic status, in whom there was actual emergence of one or more of the following teeth through the gingival tissues: the
permanent maxillary incisors\textsuperscript{(a)} and all permanent mandibular teeth except third molars. Excluded from the investigation were individuals with space deficiency for the emerging tooth and those with a history of early loss of the deciduous predecessors. The criterion of "eruption" was the tooth being through the gingiva but not more than 3 mm above the gingival level.

From her carefully conducted study, Gron concluded that permanent tooth emergence appears to be more closely associated with the stage of root formation than with the chronological or skeletal\textsuperscript{(b)} age of the child. The majority of teeth studied had attained \( \frac{2}{3} \) of root formation at the time of clinical emergence. Generally, mandibular permanent central incisors and first permanent molars had less than \( \frac{2}{3} \) – about \( \frac{1}{2} \) of root formation, while mandibular cuspids and second permanent molars were just past the stage of \( \frac{3}{4} \) of root formation.

Bjork and Helm 1967\textsuperscript{14} found with regard to the two dental development stages included in their study that eruption to the occlusal level of all the canines and premolars, especially for the girls, and eruption

\begin{itemize}
\item \textsuperscript{(a)} Maxillary teeth, other than the central incisors, were not included because of the anatomical factor for accurate radiographs with minimal distortion.
\item \textsuperscript{(b)} In Gron's study, bone age was assessed according to the Greulich and Pyle standards (1959).
\end{itemize}
to the occlusal level of all second molars, especially for the boys, could occur several years before or after maximum "puberal" skeletal growth (p. 142).

Burstone's 1963\(^3\) (p. 913) view that dental age is a poor guide clinically when estimating the developmental status of an individual appears to be well substantiated.

The findings of Lamons and Gray 1958\(^7\) also indicate that dental age and skeletal age may vary independently.

There is, however, evidently some correlation between mesial tooth migration and bodily growth and maturation. Moss, Greenberg and Noback 1959\(^8\) observed "that dental migration was completed more rapidly in cases whose rate of skeletal maturation were similarly more rapid" (p. 175).

The use of radiographs to reveal calcification of the developing teeth is also a method that may be employed to measure dental age.

The study of Gleissner and Hunt 1955\(^4\), was concerned with calcification of the mandibular first permanent molar. The investigators related this tooth's formation to osseous development and chronological age.

Twenty-five boys and twenty-five girls were examined with a right side lateral jaw film and a hand-wrist x-ray every three months from birth to eighteen
months and thereafter every six months to ten years of age. The fifteen calcification stages established by Gleiser and Hunt are illustrated in Figure 20.

Figure 20  (From Gleisser and Hunt 1955)

A tabulation of the findings regarding the calcification of the first permanent molar for the boys and girls examined follows:
<table>
<thead>
<tr>
<th>Stage of Calcification</th>
<th>Boys MEAN</th>
<th></th>
<th>Girls MEAN</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>AGE</td>
<td>S.D.</td>
<td>N</td>
</tr>
<tr>
<td>Coalescence of at least 2 centers</td>
<td>22</td>
<td>7.0</td>
<td>1.4</td>
<td>22</td>
</tr>
<tr>
<td>Outline of cusps completed</td>
<td>20</td>
<td>20.7</td>
<td>3.0</td>
<td>18</td>
</tr>
<tr>
<td>Half of crown completed</td>
<td>17</td>
<td>28.4</td>
<td>4.5</td>
<td>20</td>
</tr>
<tr>
<td>1/4 of crown completed</td>
<td>14</td>
<td>35.1</td>
<td>4.0</td>
<td>18</td>
</tr>
<tr>
<td>Crown completed</td>
<td>17</td>
<td>41.5</td>
<td>5.6</td>
<td>21</td>
</tr>
<tr>
<td>Minimal root formation</td>
<td>16</td>
<td>45.0</td>
<td>4.9</td>
<td>19</td>
</tr>
<tr>
<td>1/4 of root completed</td>
<td>23</td>
<td>69.1</td>
<td>8.1</td>
<td>24</td>
</tr>
<tr>
<td>1/2 of root completed</td>
<td>17</td>
<td>74.1</td>
<td>9.2</td>
<td>20</td>
</tr>
<tr>
<td>3/4 of root completed</td>
<td>21</td>
<td>76.8</td>
<td>8.8</td>
<td>22</td>
</tr>
<tr>
<td>3/4 of root completed</td>
<td>22</td>
<td>84.3</td>
<td>8.4</td>
<td>18</td>
</tr>
<tr>
<td>4/4 of root completed</td>
<td>20</td>
<td>90.0</td>
<td>8.1</td>
<td>17</td>
</tr>
<tr>
<td>Root canal terminally divergent</td>
<td>22</td>
<td>100.4</td>
<td>7.7</td>
<td>16</td>
</tr>
<tr>
<td>Root canal terminally convergent</td>
<td>13</td>
<td>106.6</td>
<td>7.4</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 5  (From Gleisser and Hunt 1955)

The study also showed, when comparison was made of the serial jaw x-rays and the hand wrist radiographs, that "lines of arrested growth"(a) were concomitant in tooth and bone. The delays in dental calcification were less prolonged, however, than the delays in the hand and wrist (p. 274).

Gleisser and Hunt's findings relating tooth maturation and emergence with chronological and skeletal

(a) In the teeth: lines of Retzius in the enamel, lines of Owen in the dentine, neonatal lines in the enamel and dentine, interglobular spaces in the dentine

In the long bones: radio-opaque lines which usually occur distally near the diaphyseo-eplhyseal plane.
age are illustrated in their diagram (p. 283) which is reproduced (see Figure 21).

Figure 21 (From Gleisser and Hunt 1955)
Demisch and Wartmann\(^{(a)}\) (1956) who conducted radiographic studies of a similar nature to the last mentioned, were concerned with the mandibular third molar.

The sample in this study comprised eighty-one boys and seventy girls, of the Boston area, who were studied over an eight to sixteen year age period using a seven stages schedule of calcification of the third molar. Skeletal age was assessed on hand-wrist x-rays.

Relating chronological and skeletal age, the mean difference was "0:0" in the boys and in the average girl the skeletal age was advanced "0:6" over the chronological age (Krogman 1968\(^{68}\) p. 336).

Calcification of the mandibular third molar showed a "chronological symmetry" in 71% of the boys and girls. The median chronological age and skeletal age of the third molar's stages of formation agreed closely in both sexes.

A high degree of association was found to exist between the third molar calcification and skeletal age or chronological age, as well as between skeletal age and chronological age.

Krogman 1968\(^{68}\) (p. 336) comments, "the maturation of various tissue systems seems to be time-synchronised,

\(^{(a)}\) Referred to by Tanner 1962\(^{107}\) p. 72 and by Krogman 1968\(^{68}\) on p. 336.
certainly with reference to the tooth-long bone growth and maturation timing".

Bjork, Jensen and Palling 1956\textsuperscript{15} found (p. 266) that retarded maturation of the mandibular third molar "or perhaps general retardation of dental development" is a significant factor related to prognostication of third molar impaction.

The sequence of clinical eruption of the teeth may not be the same as that of their calcification. Garn and Lewis's 1957\textsuperscript{38} study of thirty-six boys and girls concerned the order of calcification and eruption of the second premolars and second molars. Fourteen cases exhibited earlier formation of the second molar; but in only seven of these did the second molar erupt prior to the second premolar. Of the remaining twenty-two subjects in whom the second premolar was the first formed, the latter tooth also erupted earlier than the second molar in all but one of these twenty-two children (p. 994).

Garn, Lewis and Polacheck 1959\textsuperscript{40} studied the "intrinsic variability" in the formation of the first and second premolars and the three permanent molars. Beginning calcification, beginning root formation, and apical closure, were three specific stages examined in relation to the time range for formation of these teeth. See Figure 22.
Figure 22  (From Garn, Lewis and Polacheck 1959)

The findings of Garn, Lewis and Polacheck show time variability to be significantly greater than some previous reports with regard to the two premolars and the first, second and third molars. See Table 6.

The need for a measure of relative variability, "since developmental phenomena covering an 18-year range had to be compared" (p. 143), led Garn, Lewis and Polacheck to adopt the following coefficient of variation (CV) as a measure of variability:

\[
\frac{\text{standard deviation}}{\text{mean}} \quad (\frac{\text{SD}}{\text{M}}) \quad \text{or} \quad \frac{r}{x}
\]
TIME VARIABILITY OF TOOTH FORMATION

as given by various authors

<table>
<thead>
<tr>
<th>Mandibular Tooth</th>
<th>Logan &amp; Kronfeld</th>
<th>Kronfeld, Holt and McIntosh, Wilkins</th>
<th>Schour and Massler, Arey</th>
<th>Spector &amp; Polachek (Percentiles 5th-9th)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
<tr>
<td><strong>BEGINNING CALCIFICATION (YEARS)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_1$</td>
<td>1.50-2.00</td>
<td>1.75-2.00</td>
<td>1.50-2.00</td>
<td>1.75</td>
</tr>
<tr>
<td>$P_2$</td>
<td>2.00-2.50</td>
<td>2.25-2.50</td>
<td>2.00-2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>$M_1$</td>
<td>0.08-0.33</td>
<td>birth</td>
<td>birth</td>
<td>birth</td>
</tr>
<tr>
<td>$M_2$</td>
<td>2.00-2.50</td>
<td>2.50-3.00</td>
<td>2.50-3.00</td>
<td>2.75</td>
</tr>
<tr>
<td>$M_3$</td>
<td>7.00-9.00</td>
<td>8.00-10.00</td>
<td>7.00-10.00</td>
<td>7.00-10.00</td>
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<td><strong>CROWN COMPLETION – ROOT FORMATION (YEARS)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_1$</td>
<td>–</td>
<td>5.00-6.00</td>
<td>5.00-6.00</td>
<td>–</td>
</tr>
<tr>
<td>$P_2$</td>
<td>–</td>
<td>6.00-7.00</td>
<td>6.00-7.00</td>
<td>–</td>
</tr>
<tr>
<td>$M_1$</td>
<td>–</td>
<td>2.50-3.00</td>
<td>2.50-3.00</td>
<td>–</td>
</tr>
<tr>
<td>$M_2$</td>
<td>–</td>
<td>7.00-8.00</td>
<td>7.00-8.00</td>
<td>–</td>
</tr>
<tr>
<td>$M_3$</td>
<td>–</td>
<td>12.00-16.00</td>
<td>12.00-16.00</td>
<td>–</td>
</tr>
<tr>
<td><strong>ROOT COMPLETION – APICAL CLOSURE (YEARS)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_1$</td>
<td>–</td>
<td>12.00-13.00</td>
<td>12.00-13.00</td>
<td>12.00-13.00</td>
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<td>$P_2$</td>
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<td>$M_1$</td>
<td>–</td>
<td>9.00-10.00</td>
<td>9.00-10.00</td>
<td>9.00-10.00</td>
</tr>
<tr>
<td>$M_2$</td>
<td>–</td>
<td>14.00-15.00</td>
<td>14.00-16.00</td>
<td>14.00-16.00</td>
</tr>
<tr>
<td>$M_3$</td>
<td>–</td>
<td>18.00-25.00</td>
<td>18.00-25.00</td>
<td>18.00-25.00</td>
</tr>
</tbody>
</table>

Table 6  (From Garn Levis and Polachek 1959)
By a correction of .75 years the CV was corrected to conception, rather than to birth. The variability of tooth formation increased steadily with advancing median age (p. 146).

Lewis and Garn 196074 in relating tooth formation with other maturational factors have produced the following diagrammatic representation of the relative variability of osseous development, skeletal age, eruption of deciduous teeth, permanent tooth eruption, cusp calcification, completion of crown formation, menarche and apical closure. (Figure 23.)

![Figure 23](From Lewis and Garn 1960)
Dental development up till the time of eruption of the teeth is a reliable maturational criterion.

With regard to the sex difference in tooth calcification, eruption and osseous development, Garn, Lewis Koski and Polacheck 1958\textsuperscript{39} found (p. 566) that girls are on average 3\% ahead of boys in tooth calcification, 5\% ahead in tooth eruption and 10-25\% ahead in osseous development, based on calendar age from birth.

As a final statement on dental development as a meter of physiological age the conclusion of Tanner 1962\textsuperscript{107} (p. 73) is quoted "... so far as gauging physiological maturity at adolescence is concerned it is of less value than skeletal or secondary sex character age, since nearly all the teeth have calcified or erupted by the time puberty begins. But it may well be of use during the preceding years."

**GENERAL SUMMARY**

(1) Chronological age, height-weight-age tables and morphology are limited in their usefulness as clinical guides to developmental age.

(2) A child's developmental status may be assessed by using the hand-wrist radiograph after the method of Greulich and Pyle, whose standards, while not being expected to fit exactly every group of children, will nevertheless, provide a means of reference. The
maturity-indicators, which represent the order that ossification begins in the individual bones and epiphyses of the hand and wrist, are universally applicable as a reliable measure of maturational status.

Commencing ossification of the adductor sesamoid of the thumb, evidenced radiographically, has been found to relate to the onset or imminence of the circum-adolescent growth spurt. The latter is also easily detected from longitudinal records wherein annual height increments have been recorded over a long period.

(3) Dental age and skeletal age may vary independently. Eruption of the teeth appears to be more closely related to their stage of root formation than to skeletal age or chronological age.

There is some correlation between mesial tooth migration and skeletal maturation.

Calcification-stages of the teeth are a reliable measure of dental age, and are more significantly related to skeletal development than tooth eruption.

The sequence of tooth formation is not necessarily the sequence in which teeth will erupt clinically.

For gauging physiological maturity at adolescence dental development is of no value.


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54 Hammond, W.H., Measurement and Interpretation of Subcutaneous Fat, with Norms for Children and Young Adult Males, British Journal of Preventive Social Medicine, 9: 201-211, 1955.


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79 Meredith, H.V., Change in a Dimension of the Frontal Bone During Childhood and Adolescence, Anatomical Record, 134: 769-780, (Aug.) 1959.


Wolff, O.H., Obesity in Childhood; A Study of the Birth Weight, the Height, and the Onset of Puberty, Quarterly Journal of Medicine, N.S. 24: 109-123, 1955.

GLOSSARY

Articulare - Point at the junction of the contour of the external cranial base and the dorsal contour of the condylar process. (The mid-point is used at double contouring of the condyles.) (Bjork 1955\textsuperscript{12} p. 200)

Basion - The perpendicular projection of the anterior border of foramen magnum (endobasion) on a tangent through the lower contour of the foramen. (Bjork 1955\textsuperscript{12} p. 200)

Bolton Point - The highest point on the concavity behind the occipital condyles. (Salzmann 1966\textsuperscript{97} p. 153)

Bregma - The junction of sagittal and coronal sutures on the surface of the vault. (Bjork 1955\textsuperscript{12} p. 200)

Ethmoidale - The lowest median point of the contour of the anterior cranial fossa, corresponding to the cribiform plate of the ethmoid bone. (Bjork 1955\textsuperscript{12} p. 200)

Facial Plane - A line from nasion through pogonion. (Salzmann 1966\textsuperscript{97} p. 153)

Frankfort Horizontal (Cephalometric) - The horizontal plane through right and left cephalometric porion and the left orbitale. (On the profile photograph it is drawn from the superior margin of the acoustic meatus to orbitale.) (Salzmann 1966\textsuperscript{97} p. 153)

Frontale - A point on the surface of the frontal bone defined by a line projected at right angles from the
mid-point of a line connecting nasion and bregma. (Bjork 1955\textsuperscript{12} p. 200)

Gnathion - A point near the chin at the intersection of the facial and mandibular planes. (Salzmann 1966\textsuperscript{97} p. 153)

Gonion - A point on the gonial angle determined by bisecting the angle formed between the mandibular plane and the plane representing the posterior border of the ramus. (Lande 1952\textsuperscript{72} p. 81)

Lambda - The junction of lambdoid and sagittal sutures on the outer surface of the vault. (Bjork 1955\textsuperscript{12} p. 200)

Mandibular Plane - A line tangent to the lower border of the mandible at gonion and menton. (Salzmann 1966\textsuperscript{97} p. 153)

Nasion - The most anterior point of the nasofrontal suture. (Bjork 1955\textsuperscript{12} p. 200)

Opisthocranion - The most posterior point in MSP on the outer surface of the vault, defined as the largest distance from nasion (excluding the external occipital protuberance). (Bjork 1955\textsuperscript{12} p. 200)

Orbitale - The lowest point on the left infra-orbital margin. (Salzmann 1966\textsuperscript{97} p. 153)

Pogonion - The most anterior point on the midline of the mandibular bone. (Salzmann 1966\textsuperscript{97} p. 153)
Point A (Subspinale) - The deepest point on the maxillary mid-line between the anterior nasal spine and the prosthion. (Salzmann 196697 p. 153)

Point B (Supramentale) - The deepest mid-line point on the mandible between infra-dentale and pogonion. (Salzmann 196697 p. 153)

Porion - The highest point on the superior surface of the soft tissue of the external auditory meatus. (Salzmann 196697 p. 153)

Sella - The centre of the bony crypt forming the sella turcica. The surface of the sella turcica is determined independently of the contours of the clinoid processes, and is limited upward by a line from tuberculum sellae to dorsum sellae. The centre is defined as the mid-point of the greatest diameter from tuberculum sellae. (Bjork 195512 p. 200)

Sella Nasion - A plane passing from the centre of sella turcica to nasion. (Lande 195272 p. 82)

Sphenoidale - The uppermost point of tuberculum sellae in MSP. (Bjork 195512 p. 200)

Subspinale - (see Point A)

Supramentale - (see Point B)