OSSIFICATION OF THE ADDUCTOR SESAMOID AND THE
ADOLESCENT GROWTH SPURT

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INTRODUCTION

It is evident that in the adolescent child there is an acceleration of growth in the face and jaws which closely follows the same maturation scale as general skeletal growth, as represented by body height.\(^9\), \(^{11}\), \(^{72}\), \(^{90}\), \(^{107}\), \(^{108}\)

Adequate consideration of the circum-adolescent acceleration of growth in the facial skeleton is particularly warranted when planning orthodontic treatment for malocclusions associated with a discrepancy in the maxillo-mandibular skeletal relationship. For it can be expected that in approximately 9 to 12 months after the onset of the circum-adolescent statural increase, an acceleration in growth of the facial skeleton occurs with the mandibular ramus exhibiting the largest of the skeletal changes. Consequently, if the onset of the circum-adolescent growth spurt can be predicted or detected, orthodontic treatment of appropriate nature can be timed to take advantage of, or to best cope with (as the case may be) the facial skeletal changes which take place during this period of rapid development.

A significant study relative to the possibility of predicting the age at maximum adolescent growth in
statural height has been reported by Bjork and Helm (1967)\textsuperscript{14}. Their purpose was to try to relate the "circumpuberal" growth spurt to other criteria of maturation: ossification of the sesamoid bones in the thumb as evidenced in hand-wrist radiographs, stages in dental development and, in girls, the menarche. It is noted that the sesamoids of the metacarpophalangeal joint of the thumb were included as they are the only consistent ossification centres in the hand that appear near puberty.

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 metacarpophalangeal sesamoid of the thumb occurred, and also in girls the age at menarche". It was evident that the onset of ossification of the ulnar sesamoid either preceded or coincided with maximum adolescent growth. It did not take place after the circum-adolescent growth spurt and usually occurred one year before. Menarche, on the other hand, did not occur before this age and it was recorded up to a few years later. Dental development was found to be of little value as a criterion of adolescence.

Bjork points out that since growth in body height is the dimension by which maximum "puberal"
skeletal growth is most easily determined, measurement of the annual growth in body height is recommended as a routine procedure for orthodontic patients treated over a long period. Further, Bjork advocates the use of radiographic examination to determine ossification of the sesamoid to provide a guide where longitudinal records are not available. He mentions that this is easily recorded on a dental film; with the reservation that in single cases ossification of the sesamoid may not occur.

The findings arising from the study conducted by Bjork and Helm, together with their comments, provided motivation for this thesis and the related study project.

The purpose of the thesis is to review evidence that there is an adolescent spurt of growth in the facial skeleton and that the growth changes which occur are such that the adolescent growth spurt is of considerable significance in the orthodontic treatment of malocclusions wherein growth is a factor. The background for this review entails an outline description of general body growth from birth to maturity with some emphasis on cranio-facial growth. A focus of special interest is the adolescent growth spurt itself, and this will be dealt with in some
detail. Allied with growth is development, and of particular concern to this work is assessment of an individual's developmental age as distinct from his or her chronological age. It is in relation to this subject of physiological age that a report of a radiographic survey by the author is submitted concerning the ossification of one of the sesamoid bones in the thumb relative to the adolescent spurt of growth in stature height.

**Definition of Terms Relating to the Period of Physiological Change**

The acceleration of growth in height associated with adolescence, receives varied terms of description in the literature. The "circumpuberal growth spurt", the "circum-adolescent statural increase" and the "puberal growth spurt" are some examples.

Tanner 1962\(^{107}\) (p. 1) refers to the "adolescent growth spurt" during which there occurs the "peak velocity of height growth" (ibid., p. 1).

With regard to the time in adolescence when maximum velocity in height growth is reached, Bjork and Helm 1967\(^{14}\) (p. 137) use "maximum puberal growth in body height" as their description. Krogman 1968\(^{67}\) mentions the "circumpuberal increase in growth velocity" (p. 179), "circumpuberal acceleration"
(p. 181) and "circum-adolescent acceleration" (p. 183). "Adolescent" and "puberal" appear to be synonymous. There is no doubt as to the specific stage of growth being referred to. In the present study both terms are used, mainly to minimise repetition; for, the particular stage of development to which attention has been drawn is very pertinent to, and receives frequent mention in, this thesis.

However, it is acknowledged that while "adolescence" is that period of growth and development which commences at the end of childhood and continues till physical maturity, "pubescence" is a biological process within and part of, adolescence.

Crampton's (1908) definitions were adopted by Richey 1937 (p. 6) who considered them the "clearest and most logical". Thus:

"Puberty' from *pubertas*-tatis ('age of manhood') refers to that point of time when the asexual life is changed to the sexual, and the ability to procreate is established. It is not a stage or period of time, but a division line between two periods, having no more duration than the division between one year and the next..... 'Adolescence' from *adolesco*-ere, evi, adultum, (the 'period of ripening') extends from puberty to maturity..... Hence adolescence is a period of time in which certain events may take place in contra-distinction to puberty which is the
moment of beginning adolescence.....

'Pubescence' from the incohesive pubesco, ere, ivi, again denotes a process covering a period of time, the completion of which is often vaguely understood to be puberty. This is a term which is often loosely used to denote puberty, or adolescence. It should be used to mean the process of becoming covered with hair, and unless qualified should have reference to pubic pubescence alone..... The period of pre-pubescence begins at birth and ends at the beginning of pubescence..... The transition from the pre-pubescent stage to the pubescent state is gradual. It is begun by an evident and rapid growth of the fine hair apparently already present..... the second period of pubescence commences with the pigmentation of this exaggerated growth and pubescence arbitrarily ends with the appearance of the kink or twist which is definitely characteristic."
PART 1 REVIEW OF THE LITERATURE

SECTION 1 AN OUTLINE OF GROWTH FROM BIRTH TO MATURITY

A GENERAL BODY GROWTH
B CRANIO-FACIAL GROWTH
C RELATING A AND B

"Growth" is defined on page 634 in the British Medical Dictionary 1961\textsuperscript{18} as "the progressive development of a living being or part of an organism from its earliest stage to maturity including the attendant increase in size" and "Development" as "the series of changes by means of which the individual embryo becomes a mature organism" (p. 418).

Waddington (1956)\textsuperscript{109} on page 279 quotes Weiss (1949) for his concept that growth means "the multiplication of that part of the molecular population capable of further continued reproduction". Waddington stresses that a precise concept of growth "must be confined to the increase in the amount of the system which is capable of growing".

Greulich (1950) has been quoted by Seide (1959)\textsuperscript{101} (p. 801) for his interpretation: "Growth manifests itself by an increase in mass and volume as disclosed by an increase in weight and by changes in external dimensions as the child advances in age; development is the expression of those processes by means of which
it becomes progressively more mature. While growth and development proceed concomitantly in the normal child they are to some degree potentially independent processes."

Nelson 1954⁹¹ (p. 10) makes the observation that "it is not possible to distinguish sharply between the terms 'growth' and 'development', but the conjoined expression has merit in suggesting a broader scope and more complex set of factors than either term alone. Furthermore, it is now widely accepted as denoting all the chemical, physical and psychological processes which are responsible for the closely interrelated changes in the forms and functions of all the body tissues, as well as the increasing capacities and purposeful adaptations acquired in the progress toward maturity."

In this section, which is merely an outline of growth from birth to maturity, no attempt will be made to deal with chemical and psychological changes involved in the growth and development complex. Physical aspects in a general sense are those under consideration.

A GENERAL GROWTH OF THE BODY AS A WHOLE

While growth is not a continuous and uniform process from one stage of development to the next, it is also not a haphazard progress of frequent spurts
and rests. In the main, the progress of growth and development conforms to a predictable and characteristic pattern. This applies to the body generally and to each of its parts and dimensions.

Between conception and maturity the pattern of growth for most parts of the body features two periods of rapid growth with an intermediate stage, of slower and relatively uniform increase, separating them. Each of the two rapid periods involves a cycle of an accelerating rate of increase to a maximum, followed by a fast deceleration and levelling off to a slow increase, or even termination, in the part or parts concerned.

The first of the two rapid growth periods has its accelerating phase during foetal life. The subsequent decelerating phase extends throughout infancy and into the pre-school years of childhood. The second period of rapid growth spans a number of years in the second decade. It is the adolescent period.\(^{(a)}\)

Tanner 1962\(^{107}\) (p. 1) refers to the growth record of de Montbeillard's son. Although the oldest longitudinal growth study in existence, it remains

\(^{(a)}\) This stage of growth is specifically dealt with in Section 2.
Figure 1
Top: Height attained by the child at successive ages.
Lower: Increments in height from one age to another.
(From Tanner 1962)
nevertheless a very good illustration of growth pattern. The diagram (see figure 1), shows the velocity of growth decreasing from birth throughout childhood. This decrease continues until the onset of adolescence when the second significant increase in growth velocity, since conception, takes place.

The interval between the two rapid growth periods is when slow and relatively uniform progress is made. During this time weight increments tend to increase slightly while the height increments are less and less. Contributing to this, is a relative enlargement of certain parts of the skeleton evidenced by an increase in chest circumference. An increase in muscle mass and subcutaneous tissue also occurs. The changes are gradual and not conspicuous but "the total effect is to make the ten year old child appear considerably more robust than the five year old". (Nelson 1954 p. 13.) The change is usually associated with improved muscle tone and ligamentous support, with better posture and other features of body mechanics reflecting the transition.

Differences in Growth Rates of Various Parts and Tissues of the Body. Some parts or tissues participate in only one of the two rapid growth periods, while others follow a different pattern altogether. During the first rapid cycle, the brain grows very
quickly and may have ceased growth before the second cycle begins. (ibid., p. 13)

At birth the brain is approximately 25% of adult size, while the total body weight is around 5% of adult weight. Fifty per cent of post-natal brain growth occurs during the first year, with another 20% accrued by the end of the second year.

By comparison, the genital organs grow very slowly during the first decade but their development is accelerated greatly during adolescence. According to Nelson 1954\(^9\)\(^1\) (p. 13), they increase considerably in size after growth of the body as a whole has ended.

Lymphoid tissue increases at a fast rate throughout the first ten years, then gradually diminishes in actual amount. In childhood there is perhaps double the amount of lymphoid tissue present at maturity. The post-natal growth pattern for different types of tissue is illustrated in Scammon's diagram\(^{(a)}\).

The thymus gland is a very labile organ being readily influenced in its size by the nutritional status (Nelson 1954\(^9\)\(^1\) p. 14). It appears to follow the general pattern during the first five years of life, changes very little in size from 5 to 15 years, and thereafter its weight diminishes simulating more

\(^{(a)}\) Referred to by Nelson 1954\(^9\)\(^1\) on p. 13, and Tanner 1962\(^10\)\(^7\) on p. 11.
Figure 2. Growth curves of different parts and tissues of the body, showing the four chief types. All the curves are of size attained, and plotted as per cent of total gain from birth to 20 years, so that size at age 20 is 100 on the vertical scale. (Redrawn from Scammon, 1930a, The Measurement of Man, Univ. Minn. Press.)

**Lymphoid type:** thymus, lymph nodes, intestinal lymph masses.

**Brain and Head type:** brain and its parts, dura, spinal cord, optic apparatus, cranial dimensions.

**General type:** body as a whole, external dimensions (except head) respiratory and digestive organs, kidneys, aortic and pulmonary trunks, musculature, blood volume, skeleton as a whole.

**Reproductive type:** testis, ovary, epididymis, prostate, seminal vesicles, fallopian tubes.

*SCAMMON'S CURVES (FROM TANNER 1962, p. 11)*
nearly the lymphoid tissue pattern.

Subcutaneous tissue increases rapidly from birth to approximately nine months, while growth of the body as a whole is decelerating. This tissue then tends to diminish so that at five years' thickness is about half that at nine months. Prior to the beginning of adolescence it again increases in amount.

The muscles follow a growth pattern similar to that of general body growth, but lag somewhat behind the body as a whole during infancy and childhood. There is compensation when rapid muscular growth takes place towards the end of adolescence. The potential for growth of muscle probably extends well into the third decade. Activity and nutrition are factors pertinent to the natural pattern of muscular growth and development.

Nelson 1954⁹¹ (p. 36) observes, in consideration of the aforementioned differences in growth rates, that the individual is far from physical maturity at the end of adolescence when full height has been attained. Muscular development is particularly short of its potential. Adult breadth of shoulders and robustness is yet to be achieved. He also comments that although secondary sex characters of the boy or girl may have the appearance of full maturity, the primary sex organs may not have reached reproductive
Changes in body proportions. A general cephalo-caudal progression of growth pertains at successive age periods (Nelson 195491 p. 31). At birth the head is relatively large, (its circumference is approximately equal to that of the chest during the first year) while the lower extremities are conspicuously short, compared with adult proportions. Developmentally, the head at this time is more advanced than the trunk which is further advanced than the limbs.

There is a progressive change in these relations from the second half of the first year through to puberty. The growth of the extremities is more rapid than that of the trunk whose growth is in turn more rapid than the growth of the head.

Waddington (1956109 p. 293) and Tanner (1962107 p. 75) refer to Medawar's (1944) diagram to illustrate the changes in body proportions from the second fetal month to adulthood. During adolescence the trunk and the extremities grow at about the same rate but the trunk continues to grow after growth in length of the leg has ceased52, 91, 107.

The differences in segmental growth rates are reflected in the changing ratio of sitting height to total height. At birth the sitting height is estimated at approximately 70% of total height. It is about 57%
Figure 3

at three years and reduces to its minimum, around 52%, at, according to Nelson (1954 p. 15), "thirteen years in girls and fifteen years in boys". By the end of adolescence the ratio has risen again by 1% to 2%. Due to individual differences in types of body build and rates of maturation, there occur considerable variations with respect to these ratios. However, individuals tend on average to follow this index from stage to stage of development.

Normal variability of rates of growth and development. Populations which are heterogeneous will admit of wider ranges in normal variability than those which are in

(a) The sex difference is consistent with the relative developmental precocity of the female. This aspect is dealt with in Section 2.
the main of pure ethnic origin.52, 91, 107 Racial differences, familial characteristics and early and late maturing strains are factors contributing to wide individual differences in the physical measurements of children who are 'normal'. Because of this variability in all the aspects of development the norms should be considered and expressed as ranges rather than averages. Normal children can deviate considerably from the average, but the greater the deviation the more unusual or different is the child in the particular respect, when compared to his peers.

Nelson 195491 (p. 36) in dealing with post natal growth of the body in general has set out the following periods:

1  Infancy: birth to 2 years of age
2  Pre-school child: 2 to 6 years
3  School child: 6 to 10 years girls
3  School child: 6 to 12 years boys
4  Adolescence

Infancy: Although growth has entered a decelerating phase by the time of birth, it is still rapid during the first two years of life.

Weight gain during the first three months averages 1 oz per day. Thereafter, the increments steadily lessen. On average, birth weight is doubled by five months, a year is taken to triple it, and the infant is 2½ years of age before birth weight is
quadrupled. Up till nine months subcutaneous tissue increases steadily; the infant becoming increasingly more rotund in appearance. After this time the thickness of subcutaneous tissue gradually lessens with the natural change from the infant to the lithe and more active child. Shirley's motor sequence chart is an illustration of the increasing physical activity. (See figure 4.) Birth length is not doubled till approximately four years of age.

Figure 4 Shirley's motor sequence chart. (From Faegre and Anderson's Child Care and Training, 1933, by permission of the University of Minnesota Press.) (From Nelson 1954.)

Head circumference increases considerably during the first year due to the extremely rapid growth of
The rate of growth then diminishes in this dimension so that head circumference has increased 50% on that at birth, by approximately six years, when it is almost adult size.

The Pre-School Child (2-6 years): This is a period of slow growth. Weight increase is less than 5 lbs. per year. The child seems to grow more in height than in weight, appearing to be tall and thin. The rapid changes of foetal life and infancy having been completed, the child is now learning to co-ordinate the motor mechanisms. He learns to walk on a narrower base, leaving the waddling stage and assuming a posture and gait less infantile and more approaching that of the adult.

Typically, the child is constantly active during waking hours exploring the world around him. "This is a period of relative thinness, loose ligaments and limited musculature." (Nelson 1954, p. 36)

The School Child 6-10 years (6-12 years boys): During this time growth in height is increasingly slow while there is an increasingly rapid gain in weight. The child loses the thin and tall look and appears more robust than in the pre-school days. Growth generally remains slow until the onset of adolescence.

Lymphatic tissue reaches its maximum during this 6 to 10 years age period. Large adenoids and tonsils
being physiologic at this time.

Nelson 1954\textsuperscript{91} (p. 37) states "The jaws begin to grow more rapidly about four years of age, as is evident in a lengthening of the face, in a spacing of the deciduous teeth and in extension forward of the previously receding mandible". (These aspects are dealt with in more detail under "Cranio Facial Growth".)

Toward the end of the "school period" signs of commencing adolescence will be shown by those children whose relative developmental advancement rates them as early maturers.
BONE GROWTH AND MATURATION DURING CHILDHOOD

The skeleton develops according to an orderly sequence of definite and irreversible changes in its many centres of ossification. The specific occurrences, which may be detected radiographically, are significant in relation to the child's normal osseous maturation and general level of development. It will be seen in Section 4 ("Assessment of Developmental Age") that the maturative changes in the skeleton are closely related to those of the reproductive system, which are directly responsible for most of the externally discernible changes on which assessment of general bodily development is usually based. The most commonly used method of estimating physiological age is by assessment of skeletal age from a hand-wrist x-ray.

Although, by the time of birth, growth has entered a decelerating phase, it is nevertheless still rapid during the first two years. The rapidity of skeletal development in infancy and early childhood is reflected by Greulich and Pyle's (1959) standards being established for every three months from birth to eighteen months, and thereafter six monthly to five years. From five years the standards are at yearly intervals, till the commencement of
adolescence, when growth accelerates again.

The biological processes involved in the growth of bone tissue and the growth of bones as organs are adequately dealt with by Weinmann and Sicher (1955)\textsuperscript{133}. The latter authors set out the structural elements of bone tissue (page 18) and describe the processes involved in its development and growth (pp. 38–46).

It is stressed that while there is only one type of bone formation, there are two types of development of bones as organs.

The following classification of the development of bones is Weinmann and Sicher's (1955)\textsuperscript{113} (page 57).

1 Bones which are preformed in cartilage, and thus develop according to the endochondral type, are those of the axial and appendicular skeleton (with the possible exception of the medial lamina of the pterygoid process).

2 Bones which develop in connective tissue and are not preformed in cartilage are the parietal and frontal bones, all the bones of the upper face, the squama of the temporal bone, the tympanic bone, the medial plate of the pterygoid process of the sphenoid bone, and the superior part of the occipital squama.

Some of these bones, for instance, nasal bone, maxilla and vomer, develop in close proximity to the cartilaginous nasal capsule. They are, however, always
separated from the cartilage by a layer of connective tissue.

3 The mandible and possibly also the clavicle are membranous bones in which secondary cartilage develops at a later stage.

Morphogenesis of bones (p. 80), functional adaptation of bones (p. 127), functional analysis of the facial skeleton (p. 130) and reference to Wolff's Law of Transformation (p. 134) are other facets of bone biology described by Weinmann and Sicher (1955)\textsuperscript{113}.

The specific features of osseous development, which are radiographically evident, and provide an indication of the child's general level of development are set out by Nelson 1959\textsuperscript{92} (on p. 20) as follows:

1 The centres of the small bones and the epiphyses and processes of the long bones begin to show calcification in a characteristic sequence and at fairly predictable ages.

2 The relative sizes of centres of ossification and particularly the interrelations between them.

3 The stage of development of a bone recognized by shape, contours and processes: so-called maturity indicators.

4 The sharpness of outlines of end zones or growth lines and the densities of shadows in these areas.

5 The relations between epiphyses and diaphyses:
At first the breadth of the calcium-free zone between these parts is noted, but as the time of union approaches the degree of fusion becomes significant.

"The presence or absence of certain osseous centres is most significant in infancy, shapes and contours add much information in early childhood, and the relations between epiphysees and diaphyses are particularly noteworthy during adolescence" (Nelson 195992 p. 20).

The sequence of commencing ossification in the individual carpals and epiphysees of the hand and wrist are listed on p. 107 Section 4.

Heredity, in the main, controls the rate of skeletal maturation and the degree of physical growth to be attained by the individual.52, 91, 97, 107 However, the predestined pattern may become modified by environmental factors such as faulty nutrition or disease. (a) Minor general retardation or advancement may be related to genetic factors, but faulty nutrition, illness or other trauma probably account for the more marked delays in the appearance of individual centres of ossification.52, 92, 97, 107

As in other aspects of maturation, girls are more advanced than boys in osseous development. The difference, at birth, is slight but by puberty is

(a) These aspects are considered under "Factors Affecting Rate of Growth".... in Section 2.
approximately two years.\textsuperscript{52, 91, 107} Separate standards of skeletal age for boys and girls have therefore been established. Genetic differences, racial, familial and sex differences\textsuperscript{(a)} account for a wide variability among normal children of the same chronological age.\textsuperscript{52, 92, 97, 107}

"In general children tend to be average, retarded or advanced in osseous development to much the same extent at succeeding ages." (Nelson 1959\textsuperscript{92} p. 21)

Bambha and Van Natta 1963\textsuperscript{9}, found that children who are skeletally advanced mature early and have an early adolescent facial growth spurt, while children with retarded skeletal age tend to mature late. The large middle group of average maturers exhibited substantial variation. The study of the last mentioned authors is referred to in more detail under "Cranio-Facial Growth" - Section 2, p. 78.

**Somatotyping:** Sheldon et. al.\textsuperscript{(b)} developed a photographic method for classifying and describing individuals according to their characteristics of "body build". Three main forms of body build are set out, based on a seven point scale with four as the

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\textsuperscript{(a)} To which further reference is made in Section 4.

\textsuperscript{(b)} Sheldon, Stevens and Tucker (1940) referred to by Nelson\textsuperscript{91} (1954) page 47.
mid-point. It has become a useful method for describing body form.

Nelson 1954\(^1\) (p. 47), using illustrative photographs, indicates the principal characteristics of each of the three types of body build according to Sheldon's somatotype classification.

"Endomorphy: relative preponderance of soft roundness throughout the body, with large digestive viscera and accumulations of fat, usually presenting large trunk and thighs and tapering extremities.

Mesomorphy: relative preponderance of muscle, bone and connective tissue, with heavy, hard physique of rectangular outline.

Ectomorphy: relative preponderance of linearity and fragility, with large surface area and thin muscles and subcutaneous tissue."

All individuals combine some degree of all three components of build and most are not conspicuously dominant in any one. Some people do show a dominance of features of one type, or a high degree of two types with a minimum of characteristics of the third type. Body type is primarily a constitutional attribute and is not often clearly manifest in early childhood except where there is a marked dominance of pattern. Usually the body type is not fully established until adolescence.
Lindegard 1954\textsuperscript{75}, who studied the nature of body build variations, variations in skeletal build, amount of soft tissue, sex differences in body build, and body build as a whole, summarised his findings thus: "An individual with a large length factor and an average sized sturdiness factor is characterised by long extremities, a broad deep and long trunk skeleton, flattened cranial base form, high upper face and long mandible (as measured by the chin-condyle distance)." "An individual with a large sturdiness factor, but average sized length factor, shows the following features: long hands and long feet, broad chest, large bi-acromial and bi-iliac breadths, large brain case, large cranial base length and large face length."

The various factors which may influence growth and development are described under "The Adolescent Growth Spurt".

B  CRANIO FACIAL GROWTH

Many important studies of cranio-facial growth have been reported in the literature. Some investigators have been concerned with the overall topographical changes that take place in the skull. The longitudinal studies of Tirk (1948)\textsuperscript{108}, Bjork (1951)\textsuperscript{11}, Lande (1952)\textsuperscript{72}, Brodie (1953)\textsuperscript{20}, Bjork (1955)\textsuperscript{12}, Nanda (1955)\textsuperscript{30}, and Bamhha and Van Natta (1963)\textsuperscript{9}, all employed serial lateral head x-rays to show the changes that occur. The actual bone processes associated with the growth changes have been studied by others: Scott (1956)\textsuperscript{99}, Scott (1958)\textsuperscript{100}, Ford (1958)\textsuperscript{36}, Enlow and Harris (1964)\textsuperscript{34}, Enlow and Bang (1965)\textsuperscript{33}, Enlow (1966)\textsuperscript{32} et. al.

The contribution of function as an essential element to the achievement of normal growth potential has been demonstrated by Weinmann and Sicher (1955)\textsuperscript{113}, Moss (1960)\textsuperscript{83}, Moss (1962)\textsuperscript{84}, Moss and Greenberg (1967)\textsuperscript{86}, Moss and Rankow (1968)\textsuperscript{89}.

From a review of the literature cited, there are some significant features of cranio-facial growth which are summarised as follows.

Summary of Cranio Facial Growth

1. Growth of the calvarium is in response to the increasing size of the neural contents.\textsuperscript{36, 47, 64, 83, 84, 113}
The shape of the brain case may be influenced by the growth pattern of the cranial base. The anterior part of the cranial base is closely related to the development and growth of the upper facial skeleton. After fusion of the sphenoorbital suture at about 7 years, the anterior cranial base, i.e. from sella turcica to foramen caecum, remains stable. However, the sella-nasion dimension is prone to change up to maturity. The upper face increases in depth and height by growth of the nasal septum and the sphenoorbitalcic-tomaxillary suture system. After closure of the suture system at approximately seven years, the upper face grows by surface apposition and modelling resorption of bone, with the upper teeth erupting and migrating downward and forward in co-ordination with the "changing spatial position of the lower teeth". There are two general vectors of cranio-facial growth intimately concerned in the developing skeletal and dental relationships and the facial pattern. The sphenoorbital synchondroses carries the maxillary complex in an upward and forward direction. Growth of the developing mandible conveys the lower dental arch downwards and forwards. Between the two diverging vectors, space is created for vertical
facial development, tooth eruption and alveolar growth.\textsuperscript{26}

Co-ordinated Maxillary-Mandibular Growth

It is evident that there are two main factors concerned in co-ordinated maxillary-mandibular growth:
1 The timing of closure of the synchondroses and sutures related to the maxillary growth complex.
2 The growth pattern of the mandible.

With regard to (1) there is general agreement\textsuperscript{26, 36, 64, 100} that fusion of the parts of the cranial base occurs as follows:
1 The two parts of the sphenoid bone have united by birth
2 The mesethmoid unites with the facial parts of the ethmoid with ossification of the cribiform plate between the first and third year
4 The sphen-o-occipital synchondrosis does not fuse till about the seventeenth to twentieth year.
The chronological ages given may be regarded as only a guide. Konie's (1964)\(^6\)\(^3\) findings\(^{(a)}\) showed that fusion of the sphenop-Occipital synchondrosis is related to the rate of skeletal maturation. He noted that fusion commenced approximately six months before the adductor sesamoid was radiographically evident based on the Greulich and Pyle standards.

Melsen (1969)\(^7\)\(^7\) studied closure of the sphenop-Occipital synchondrosis by direct inspection of 132 dried skulls from India. The skulls of various age groups were classified according to the dental development as defined by Bjork, Krebs and Solow (1964). Melsen found (p. 87) that closure of the synchondrosis occurred after the eruption of all canines, premolars and second molars. If the findings of Konie and Melsen are to be oriented to puberty, attention is drawn to the study of Bjork and Helm (1967)\(^1\)\(^4\).

The latter authors, while deciding that ossification of the adductor sesamoid always occurred before maximum "puberal" skeletal growth, also concluded that eruption to the occlusal level of all canines and premolars, especially for the girls, and eruption to the occlusal level of all second molars,

\(^{(a)}\) See page 106 Section 4 - Assessment of Developmental Age.
especially for the boys, in their sample(a), could occur several years before or after maximum "puberal" skeletal growth.

2 Concerning mandibular growth, it will be seen in Section 2, where reference is made to several longitudinal growth studies that there occurs an acceleration in the growth of the lower jaw closely following the circum-adolescent statural increase. The largest of the skeletal changes is registered in the ramus.

(a) Danish school children: 20 girls and 32 boys.
C RELATING CRANIO FACIAL GROWTH AND GENERAL BODY GROWTH

The progressive change in the relationship of head size to the body and limbs from birth through to maturity is illustrated in figure 3 page 16. The differential growth rates of the limbs, trunk and head responsible for the changing proportions during developmental progress, have also been referred to.

While the brain and calvarium follow the neural pattern of growth and the facial skeleton, in general, appears to approximate the general skeletal rate of growth, the cranial base as a whole seems to follow a pattern between the neural and the general (Ford 1958 p. 503). However, individual parts of the base have either the neural or the general skeletal growth rate, but not an intermediate one.

Scott 1958 (p. 323) provides a table showing

<table>
<thead>
<tr>
<th>AGE</th>
<th>BODY LENGTH</th>
<th>CRANIAL BASE (B-N)</th>
<th>HEAD CIRCUMFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth</td>
<td>28</td>
<td>55 (21)</td>
<td>65</td>
</tr>
<tr>
<td>2 yrs.</td>
<td>50</td>
<td>70 (22)</td>
<td>90</td>
</tr>
<tr>
<td>4 yrs.</td>
<td>59</td>
<td>75 (15)</td>
<td>93</td>
</tr>
<tr>
<td>6 yrs.</td>
<td>66</td>
<td>80 (15)</td>
<td>95</td>
</tr>
<tr>
<td>8 yrs.</td>
<td>72</td>
<td>86 (32)</td>
<td>97</td>
</tr>
<tr>
<td>10 yrs.</td>
<td>78</td>
<td>89 (12)</td>
<td>98</td>
</tr>
<tr>
<td>12 yrs.</td>
<td>85</td>
<td>90 (12)</td>
<td>99</td>
</tr>
<tr>
<td>15 yrs.</td>
<td>91</td>
<td>91 (10)</td>
<td>99.6</td>
</tr>
<tr>
<td>18 yrs.</td>
<td>98</td>
<td>96 (8)</td>
<td>99.8</td>
</tr>
</tbody>
</table>

1 Data for body length and head circumference from Kornfeld in Krogman ('41).
2 Figures in parentheses = number of skulls measured.

Table 1 (From Scott 1958)
body length, cranial base length (basion to nasion dimension) and head circumference, expressed as percentages of adult proportions for various ages from birth to 18 years.

With regard to the cranial base itself, Scott's\textsuperscript{100} table (Table 2) records the growth of its particular segments.

The figures he gives are his actual measurements. It is evident that while the basion to pituitary point dimension and foramen caecum to nasion dimension, show a growth pattern similar to that of the cranial base as a whole, the ethmoidal section reaches adult proportions by about the seventh year(a).

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
\textbf{AGE} & \textbf{B-N}\textsuperscript{1} & \textbf{B-P}\textsuperscript{1} & \textbf{P-C}\textsuperscript{1} & \textbf{C-N}\textsuperscript{1} \\
\hline
Birth to two weeks (4)\textsuperscript{2} & mean 54 & 22 & 29 & 4 \\
 & range (48-58) & (21-23) & (35-32) & (3-5) \\
1-3 yrs. (16) & mean 78 & 32 & 39 & 7 \\
 & range (68-79) & (28-35) & (34-44) & (4-8) \\
4-7 yrs. (11) & mean 80 & 35 & 44 & 9 \\
 & range (72-91) & (31-38) & (40-48) & (7-11) \\
8-13 yrs. (12) & mean 90 & 42 & 46 & 10 \\
 & range (88-96) & (38-45) & (43-50) & (9-12) \\
14-20 yrs. (15) & mean 97 & 46 & 47 & 14 \\
 & range (86-106) & (43-49) & (45-50) & (11-20) \\
Adult M + F & mean 98 & 47 & 47 & 16 \\
\hline
\end{tabular}
\caption{Growth of cranial base segments}
\end{table}

\textsuperscript{1}B = basion, P = pituitary point, N = nasion, C = foramen caecum.
\textsuperscript{2}Figures in parentheses in first column = number of skulls measured.

\textbf{Table 2 (From Scott 1958)}

(a) De Coster 1951, Scott 1954 and Bjork 1955 are also referred to by Scott (1958)\textsuperscript{100}.
A serial investigation of facial and skeletal growth in 7-12 year old children was carried out by Pike (1964)\textsuperscript{94}. The subjects were "fourteen boys and eleven girls", ..... "with a negative medical history, acceptable dental development, and no previous orthodontic treatment" (p. 469). For each child four annual lateral roentgenograms were taken and statural determinations made. From lateral head tracings, two antero-posterior and two vertical parameters located in the facial skeleton were measured to the nearest .5 mm.

The dimensions examined were mandibular length, maxillary length, total anterior facial height and ramus height. Statural height was measured to the nearest millimetre.

Pike found from his investigation that "all individuals demonstrated a close approximation to constancy in the growth rates of statural and facial skeletal dimensions studied" (p. 469). The study also indicated a positive correlation between the rate of statural growth and growth rates of the facial skeletal dimensions examined. However, the magnitude of correlation was not sufficient to permit a highly accurate prognosis of facial skeletal growth-rate from a computation of the statural rate of increase.
The findings of Nanda (1955)\textsuperscript{90}, Bambha (1961)\textsuperscript{7} and Bambha and Van Natta (1963)\textsuperscript{9} (whose studies are described in Section 2) also demonstrate how growth of the facial skeleton is related to the general skeletal rate of growth.

Krogman (1968)\textsuperscript{69} concludes (p. 381) that the upper one third of the face seems to follow the neural growth pattern (it being about completed by approximately seven years) while the lower two thirds is influenced by the general skeletal growth and continues growing to maturity. This conclusion regarding the upper one third of the face is consistent with Scott's (1958)\textsuperscript{100} findings concerning the ethmoidal section of the cranial base and the closure of the "spheno-ethmoidal-circum-maxillary suture system" as described by Coben (1966)\textsuperscript{26}.

The aspect of facial skeletal growth being related to the rate of statural increase is a facet of maturation which is described in "Assessment of Developmental Age" - Section 4.
SECTION 2  THE ADOLESCENT GROWTH SPURT

It is proposed to treat this section under the following headings:

A  GENERAL DESCRIPTION
B  METHODS OF GROWTH STUDIES
C  AN OUTLINE DESCRIPTION OF GENERAL BODY GROWTH
D  FACTORS AFFECTING THE ADOLESCENT GROWTH SPURT
E  CRANIO-FACIAL GROWTH

A  GENERAL DESCRIPTION

The adolescent growth spurt is a constant phenomenon which occurs in all children, though its time of onset, intensity and duration varies from one child to another. During this period of accelerated growth the child undergoes physical and mental changes within an overall process of transition to maturity. The more noticeable and significant changes are physical, and physiological. There is an acceleration in growth of all muscular and skeletal dimensions, and the reproductive organs, in particular, enlarge. The parallelism of the reproductive and skeletal systems' status of development is mentioned in Section 4. This co-ordination is markedly demonstrated during adolescence when both systems have accelerated development towards the mature state.

In most individuals head diameters have some
degree of increased growth rate, the cartilages of
the wrist grow and ossify more rapidly, and the heart
grows faster, as do the abdominal viscera. Brain
size does not seem to alter but structural changes
may occur at an accelerated rate. There is a decrease
in lymphatic tissue and diminishing of subcutaneous
fat on the limbs.

Scammon's illustration of the growth of different
parts and tissues has been quoted\footnote{67, 107} to indicate
how the adolescent spurt of growth is related to the
general development from birth to maturity, (figure 2,
p. 13, Section 1). The early growth in brain size is
represented, the lymphatic tissues enlargement during
mid-growth years and subsequent fading away; and the
general growth curve apart from the head.

**Sex Difference:** Prior to the adolescent growth spurt,
boys and girls are more or less the same height.
However, girls, being more precocious\footnote{52, 107} in their
development towards maturity, reach their adolescent
growth spurt approximately 2 to 2½ years ahead of
boys. Then having a somewhat less intense spurt in
statural height and because she commences and finishes
this final phase of growth earlier, the average female
will not have achieved the same height when matured as
the average fully grown male. On an average, girls
experience their adolescent spurt between 10½ and 13
years of age and attain a maximum height increment of 8 cm per year. Boys commence adolescence between 13 and 15 years and during this period of marked acceleration in growth, may have a height gain of 20 cm, (10 to 30 cm range) with an average peak velocity of 10 cm per year. Weight gain during the period may be up to 20 kg.

Figure 5  Adolescent spurt in height growth for girls and boys. The curves are from subjects who have their peak velocities during the modal years 12-13 for girls and 14-15 for boys. (Actual mean increments, each plotted at centre of its ½-year period. Data from Shuttleworth, 1939, Tables 23 and 32.)

(From Tanner 1962)
B METHODS OF GROWTH STUDY

Many investigators in the field of human growth study have suggested various methods or equations to illustrate graphically the variable velocities of growth relating to the individuals' progress to physical maturity. Tanner 1962\textsuperscript{107} (p. 8) refers to Backman's effort to divide growth into three cycles.

1 Primordial: The cycle responsible for most of the growth from one month post-fertilization to 2 years after birth. The maximum velocity being at about mid-pregnancy.

2 Infantile: From 2 years to adolescence. Maximum velocity being at approximately 2\(\frac{1}{2}\) years.

3 Juvenile: The adolescent spurt; beginning gradually, however, at about 7 or 8 years.

The three growth curves pertaining to these cycles are of the same form, fitting to the velocity rather than to the distance.

Tanner would endorse Backman's method "if a physiological interpretation could be given to the first and second cycle," \ldots\ "perhaps through the second reflecting growth hormone action\ldots\" (p. 8).

Two methods of survey are available for the collection of data for growth study: Cross-sectional and Longitudinal. According to the information
requirements appropriate to the study is the choice of method made.

1 **Cross-sectional Study:** In this method each individual is measured once only. A study of birth to old age can be done in a short time, e.g. a year, to produce a distance curve of growth. It is a relatively cheap and quick method enabling assessment of the mean ages of reaching a particular maturational stage, e.g. the eruption of a particular tooth; menarche and so on.

2 **Longitudinal Study:** is a long term study of individuals in which each subject is measured at regular chronological intervals and a log of his or her developmental progress, and rate thereof, is established.

   To estimate the variability in each velocity of growth from one year to another of an individual, and when comparing growth rates of boys and girls over a particular stage of development, longitudinal study is obviously necessary.

   A longitudinal study may be conducted over a period of two years and upwards. Over long periods some children inevitably leave the study, and others, if it is desired, join it. When these short term subjects are measured at least twice their records are part of an overall mixed longitudinal study. Usually, purely longitudinal study is arrived at by selecting the records of the full term subjects from a mixed
longitudinal study.

A true individual growth curve compiled over a long period - say up to eleven years as in the Harpenden Growth Study\(^{(a)}\) - is desirable when the growth processes of one child are to be compared with that of another.

The fact that individuals reach their adolescent growth spurt at varying times precludes the use of cross-sectional data when a study of growth at adolescence is being conducted. Comparison of individual growth curves of the adolescent spurt are tenable without regard to chronological age of onset. This is demonstrated by Tanner's 1962\(^{107}\) figure 3 (p. 9) - see figure 6.

Figure 6a records a series of individual velocity-of-growth curves in which the children commence their adolescent growth spurt at various chronological ages. The mean curve of these obtained by treating the values cross-sectionally and simply taking the average values at each age is represented by the dotted line. Obviously this is not a true representation of the average velocity curve. The adolescent spurt is smoothed out - being spread along the time axis.

In figure 6b, however, the same curves have been arranged so that their points of maximum velocity

\(^{(a)}\) As quoted by Tanner 1962\(^{107}\) (p. 6)
coincide and so the average curve in this case is characteristic of the group.

Figure 6  Relation between individual and mean velocities during the adolescent spurt. In figure 6a left, the height curves are plotted against chronological age; in figure 6b right, they are plotted according to their time of maximum velocity. (After Shuttleworth, 1937.)

(From Tanner 1962)
With regard to the spurt in physical growth at the adolescent period, there is a fairly regular order in which the various dimensions accelerate. Leg length as a rule reaches its peak first, then some four months later, hip width and chest breadth, followed after a further few months at least in the case of boys, by shoulder breadth. Trunk length and depth of chest are the last of the skeletal measurements.

The leg is regarded by Tanner as having a definite gradient of timing: the foot has a small acceleration about six months before the calf and thigh. Foot length is probably the first skeletal dimension below the head to cease growing, but foot breadth measured externally at heel and sole seems to continue growing for a year or more after foot length has stopped. Meanwhile calf length has accelerated a little before the thigh.

The peripheral parts of the limbs are apparently more advanced throughout growth than the proximal. In the arm, the forearm reaches its peak velocity about six months ahead of the upper arm. The two constituents of stature, total leg length and trunk length reach their individual peak velocities of growth about a year apart and so the peak of stature velocity lies between the two. However, the spurt in height is due more to the increase in trunk length than the lengthening of the
leg, and therefore the trunk-length to leg-length ratio always increases during adolescence.

The muscles reach their peak spurt of growth about three months after peak height-velocity. (a) The weight peak occurs about six months after the height peak, and the peak in strength gain about fourteen months after the height peak. Heart muscle responds to the adolescent stimulus to the extent in boys that the transverse diameter increases at its maximum rate coincidental with the maximum statural increment. Tanner comments (p. 18) that the data on which this observation is based were derived from mixed longitudinal survey though reported in a cross-sectional way. (Figure 7)

A similar adolescent spurt in heart muscle growth occurs in girls but to a lesser extent. The acceleration in heart and limb muscles is thought to be due to an increase in volume of each cell rather than that new cells are formed.

Abdominal Viscera: The data available in this respect is of cross-sectional nature and though extensive, even the most reliable is not sufficient to establish with certainty that a spurt of growth occurs during adolescence. (Tanner 1962\textsuperscript{107} p. 18.) The observations of

(a) Tanner 1962\textsuperscript{107} (p. 13) quoting the conclusion of Tanner and Robinson unpublished.
Figure 7. Velocity curves of transverse diameter of the heart, measured by x-ray, for seventy-one boys. Mixed longitudinal data, reported cross-sectionally. Height curves of same boys given above for comparison. (Data from Maresh, 1948.)

(From Tanner 1962)

Scammon\(^{(a)}\) indicate, however, that a spurt does occur in the liver, kidneys, pancreas, the non-lymphatic portion of the spleen and probably the stomach and intestines.

**Lymphatic Tissue and Thymus:** actually decreases during adolescence. In obtaining reliable data on this tissue, difficulty is experienced because of the ready reaction of lymphatic tissue to infection or stress. However, it

\(^{(a)}\) Quoted by Tanner 1962\(^{107}\) (p. 18)
is evident that the weight of the thymus increases from birth up to a maximum in the 11 to 15 years age range, thereafter greatly decreasing; the involution taking place at the time of the adolescent spurt. Tomographic x-rays indicated that in girls the width of the thymus shadow was greater (6.1 cm) pre-menarchal than after menstruation (5.4 cm); and in boys the widths 6.4 cm "pre-pubescent" and 5.3 cm "post-pubescent". (ibid. p. 19). In other organs such as the spleen, intestine, appendix and mesenteric lymphnodes, the lymphatic tissue decreased in volume during the same period. In commenting on the relation of the lymphatic system to the manufacture of antibodies, Tanner points out that the titre of blood group agglutinins follows the lymphatic curve during growth; the highest titre being found in the 5 to 10 years group with a fall to the 10 to 15 years age range (p. 19).

**Subcutaneous Tissue:** It is evident that the width of subcutaneous fat over all parts of the body decreases steadily in absolute amount from approximately one year to about the sixth to eighth year and from then on increases slowly. In the case of girls, the increase is continuous through to maturity. In boys the increase lasts till adolescence when another decrease in the thickness of limb fat occurs. For about a year or so before the height spurt starts in boys, the fat
increases. This is easily discernible in perhaps two-thirds of boys and probably to some extent in all. The increased fat retention lasts about two years; then as the general adolescent growth spurt gets way on, there is a thinning of the fat layer in the limbs with frequently a loss or a check to the fat gain in the trunk. As the adolescent spurt is completed, fat is gained once more in the trunk but the thinning of fat, which has occurred in the limbs, may persist for several years after adolescence.

With girls, the retention of fat is less variable than in boys. From birth girls have more subcutaneous fat than boys at all ages, and particularly from the fifth to sixth year onwards. At about six years, their subcutaneous layer-thickness increases steadily in both limbs and trunk - in the latter proportionately more so. Adolescence brings little interruption to this except for a temporary check to the rise in the arm, corresponding to the drop that occurs in boys at this stage.

**Development of the Reproductive System**

Prior to adolescence, the reproductive organs grow very slowly but during this period there is a marked acceleration of growth. This is spectacular and closely allied to the adolescent spurt in the skeletal system and muscular dimensions.
Although the age at which adolescence may commence varies greatly, the sequence of events during the period of physiological change is much less variable. The variability in the age of onset of adolescence is such that a group of 14 year old boys will consist of some individuals who are physically mature, while there are others who are definitely pre-adolescent. Ranged between these early and late maturers will be probably the bulk of the group who are at different stages of developmental progress through the adolescent period.

Similarly in girls there is a large variation in the ages at which adolescence begins. Some will have completely finished adolescence while others of the same chronological age may not have commenced. However, as already mentioned, the developmental progress of girls is more rapid right from infancy onward, so that they reach adolescence approximately two years ahead of boys. Greulich and Pyle established two separate standards because of this sex difference. The skeletal status of 13¾ year old girls was not equalled by boys of the same group till 15½ years of age.

The signs of adolescence are quite evident to members of the medical and allied fields. An assessment of whether a child is adolescent or not would only be difficult in the early stage or where a possible
hypogonadal⁵² state pertains. More accurate assessment of how far through the adolescent period a particular child has progressed is frequently required, however, for clinical and research work and various rating systems for this have been proposed. A simple and practical scheme is based on genital development and pubic hair development, rated separately for boys; and breast development and pubic hair development also rated separately for girls. The ratings are all on a scale from 1 (pre-adolescent child) to 5 (adult characteristics).

The standards for pubic hair can be made the same in both sexes. Accuracy in applying the standards is naturally greater in longitudinal study since they are really based on change occurring from a previous state. However, as Burstone (1963)²³ pointed out (p. 915), "From the point of view of the orthodontist, evaluation of secondary sex characteristics is either not a practical guide or is not definitive in evaluating the status of the patient relative to his peak velocity". It seems appropriate that such aspects need only be treated with brief description in this paper.

In boys the first sign of impending puberty is an acceleration of growth of the testes and scrotum and a slight growth of pubic hair at about the same time; but such proceeds slowly until the advent of the general
spurt when the pubic hair passes fairly rapidly through the further stages of its development.

In the female the first sign of adolescence is usually the appearance of the breast bud, though pubic hair is sometimes the earliest manifestation. Tanner 1962\textsuperscript{107} (p. 32) describes the five stages in the development of the reproductive system of both boys and girls with serial photographs illustrating the genitalia rating and pubic hair rating.

The sequence of events in adolescence in boys is illustrated by Tanner's diagrams:

![Diagram of sequence of events in adolescence in boys](image)

Figure 8 Diagram of sequence of events at adolescence in boys. An average boy is represented; the range of ages within which each event charted may begin and end is given by the figures placed directly below its start and finish.

*(From Tanner 1962)*
And similarly for girls:

![Diagram showing age of pubic hair, breast development, menarche, and height spurt](image)

Figure 9  Diagram of sequence of events at adolescence in girls. An average girl is represented; the range of ages within which some of the events may occur is given by the figures placed directly below them.

(From Tanner 1962)

It is noted that menarche occurs after the apex of the height spurt has been passed.

Deming's 1957\textsuperscript{29} longitudinal study indicated (p. 112) that menarche occurred "without exception, a number of months after the point of maximum rate of growth..." This conclusion bears out the finding of Boas 1932\textsuperscript{17} (p. 311).
D    FACTORS AFFECTING THE RATE OF GROWTH AND THE ONSET OF ADOLESCENCE

The time and character of the adolescent growth spurt seem to be related: the earlier the spurt the more intense it is, (Boas 193217 p. 336, and Shuttleworth 1937102 p. 188). In early maturers the process is evidently quicker, more intense, and a greater contribution to the total adult height is made, although less time is taken. This applies also to other skeletal dimensions, even to the slight growth in head width. (Goldstein 193945 p. 218.)

Early and late maturers have physique differences which are discernible before adolescence has commenced and after its completion. During adolescence such differences are obscured or magnified by virtue of the early maturers being larger than those who mature late. Tall boys and girls are likely to commence adolescence earlier than short ones, (Boas 193217 p. 317 and p. 349). Although the early maturers are probably further along their growth curves, even some time before puberty, physique differences still occur at maturity. In Shuttleworth's 1939 study103, early maturing girls and boys were, at age 6 years, heavier per centimetre of sitting height, leg length and thickness. The differences increased to their maximum at age 12.5 years in the girls and 14 years in the boys (p. 148).
Richey's 1937 study of early menarche (before 13 years) average (13-14 years) and late menarche (after 14 years) groups of girls indicated the early menarches being greater in height (p. 33) and weight (p. 23) at 6, 7 and 8 years. They were large girls before puberty in regard to both height and weight. At maturity however, there was no height difference between the three groups (p. 37). Late maturers have been found to be actually slightly taller (Stone and Barker 1937a p. 26), due mainly to leg length, (Shuttleworth 1939 p. 77). The latter mentions "this tendency is particularly clear" in the case of boys. Acheson and Dupertius 1957 found (p. 190) from their study of 225 boys, mesomorphy to be associated with early adolescence and advancement in growth, judged by skeletal age of the hip and pelvis. Ectomorphy predisposed late maturity and retarded development.

Fat: Garn and Haskell 1960 (p. 750) found that early maturers have more subcutaneous fat at all ages from 7½ years to 'puberty'. With regard to obesity, Wolff 1955 (p. 121) reported girls and boys attending a clinic for obesity, being advanced when compared to non-obese children of the same age. In both sexes, the obese children commenced 'puberty' approximately one year earlier than normal children of average height but only six months ahead of normal children of above-
average height for their age.

Notwithstanding the aforementioned remarks, the adolescent growth spurt, whether early or late, does not cause any radical change in body build. It adds only the finishing touch to a body pattern which is recognizable years before. (Tanner 1962\textsuperscript{107} p. 104)

There are various factors known to affect the rate of growth and development and hence the time and perhaps the character of the adolescent growth spurt.\textbf{Orthodontic Significance of Factors Affecting Growth}

In so far that these factors affect growth, they can indirectly influence orthodontic treatment, e.g. in consideration of a skeletally retarded child who has a Class II malocclusion associated with a small or retruded mandible, factors (e.g. malnutrition) responsible for the slowed skeletal development have orthodontic significance from two aspects:

(1) The child's malocclusion may be due to, or is at least accentuated by, the retarded mandibular growth.

(2) A delayed onset of adolescence (due to the slow rate of development) affects the progress of the child's orthodontic treatment, for the expected acceleration of mandibular growth
usually related to adolescence\(^{(a)}\) is similarly deferred.

**Genetic Control:** Fundamentally the control of the rate of development is genetical, and growth and development is to a pre-destined pattern\(^{52, 92, 97, 107}\). The entire accomplishment of this pattern will be achieved in the pre-destined time and manner providing environmental factors so contribute as to produce and maintain that state which is 'normal' for the growing individual.

**Nutrition:** Nutrition is one of the most important factors concerned in rate of growth\(^1, 107\). Studies of the effects of famine associated with war (Widdowson and McCance 1954\(^{115}\)) show that malnutrition during childhood delays growth, and in the years preceding adolescence delays the onset of the spurt. When the adverse conditions are not too severe, or over-prolonged, the organism slows up its growth awaiting better times; when such arrive, growth accelerates to a marked degree till the animal returns to its genetically determined growth-curve, along which it proceeds as before. (Acheson and MacIntyre's 1958\(^5\) experiments with rats endorse (p. 44) the above findings.) During a period of malnutrition when the body is growing more slowly, adolescence is deferred until the required level of

\(^{(a)}\) See "Crani-ofacial Growth at Adolescence"

(Section 2)
maturity is reached appropriate to its commencement (Tanner 1962\textsuperscript{107} p. 123). There is little evidence to show whether malnutrition in man alters the proportions or shape of the body.

**Effects of Malnutrition and Illness on Bone Growth and Maturation:**

Acheson 1960\textsuperscript{1} (p. 84) contends that while there may be cessation of linear growth at the epiphysis during illness or malnutrition, maturation of the bone may continue. It would seem then that some stunting as an adult could follow starvation or illness during childhood when considering that if full maturity of the epiphysis has been reached no further growth can take place.

While the findings of Hewitt, Westropp and Acheson 1955\textsuperscript{56} (p. 185) tend to support this suggestion, no evidence of a dissociation between growth and maturation is shown in the conclusion of Widdowson and McCance 1954\textsuperscript{115} (p. 127). Follis and Park 1952\textsuperscript{35} (p. 723) and Park 1954\textsuperscript{93} (p. 281) maintain that chondrogenesis and osteogenesis are separable and that the transverse lines of increased density, often radiographically-evident in children's bones are due to a dissociation. Although these scars are seen not infrequently in malnutrition and illness in some children, they are absent from others suffering severe
and prolonged illness (Jones and Dean 1956p. 67), and yet present in children with no history of illness at the relevant time. In either case they are more frequently seen in children under eleven years than those approaching adolescence. Tanner 1962 p. 130 suggests that the 'scars' represent a disturbance in growth which may follow any stress sufficient to affect the level of secretion of the anterior pituitary.

There is a great individual variation in reaction to illness. Some children show a depression of growth following a severe measles attack or pneumonia while others apparently experience none at all.

Tanner 1962 p. 132) "it is the reaction of the endocrine system to the stress which governs whether growth will slow down or not, and this in turn depends on individual constitution and on nutritional and other circumstances, as well as on the magnitude of the stressor".

Major illness may cause a slowing of both growth and maturation. The degree of such retardation is frequently an index of the severity of the illness and may be useful in prognosis. With recovery, a catch-up period of growth ensues, the rate thereof being possibly twice that of the normal for the age concerned. The studies of Milne 1951 (p. 205), Warkany, Guest and Cochrane 1955, and Warkany and Salkirk 1955.
indicate that proportions are far less affected than over-all bodily growth.

**Sex Difference in Ability to Withstand Malnutrition or Illness in Regard to Growth Rates:**

Girls' growth processes have greater resistance to stress than boys. Greulich's survey (1951)\(^5\) on Guam in 1947 revealed that all the children examined were retarded in height, weight and skeletal maturity due to wartime hardship, but girls in all respects were less retarded than boys, (p. 69). Girls return more swiftly to their normal growth when placed on supplemental diet. They are less affected by poor home conditions (Acheson and Hewitt 1954\(^4\) p. 64). Boys' growth is retarded to a greater and more variable degree by illness than girls, (Hewitt, Westropp and Acheson 1955\(^5\) p. 185).

The sex difference, it has been suggested, is due to females being better 'canalized' (Waddington 1957\(^11\) p. 19) in growth and not just having a better resistance to adverse conditions. Experiments on rats (Acheson and MacIntyre 1958\(^5\) p. 44) substantiate this conclusion. The degree of reaction of the pituitary and other endocrine glands may be the chief immediate pertinent factor.

**Climate and Race:** The indications are that climate seems to have no marked effect on the overall growth
rate, while the effect of race is difficult to assess because of the nutritional and socio-economic factors also involved. Wide differences in nutritional states have significant influence on the time of adolescence, however. Ellis 1950\textsuperscript{31} p. 86 gives the mean age at menarche in Nigerian school girls of upper socio-economic class as 14.22 years while Levine(1953\textsuperscript{73} p. 252) found that 14.42 years was the mean age for Alaskan Eskimo girls. The times of reaching the various stages of adolescence in males were also similar in Nigeria and England according to Ellis 1950\textsuperscript{31} (p. 88). Ito 1942\textsuperscript{59} (p. 346) found that Japanese reared in California reached menarche 20 months earlier than those in Japan regardless of whether they were born in Japan or in the United States (p. 346). This finding is endorsed by Greulich's 1957\textsuperscript{51} study in which Japanese born and reared in California had a skeletal age 1 to 2 years in advance of contemporary Japanese in Japan, and in fact, virtually identified with the skeletal age of Californians of European origin (p. 504). Body size of the Californian Japanese was also greater than their homeland counterparts with the ratios of leg-length to trunk, and weight to height, being consistent with their racial characteristic (p. 514).
However, concerning Race, Tanner 1962\textsuperscript{107} (p. 107) states that differences in growth rate both in size and proportion do exist irrespective of environment. Kraus 1954 (quoted by Tanner 1962\textsuperscript{107} p. 107) compared children of three American Indian tribes living in Arizona with local American whites in the 6 to 11 years group. Despite being in poorer economic, and probably worse nutritional, circumstances, the Indian children at all ages were 'heavier for their height' (p. 107) than the whites. Similarly, Maori (Tanner 1962\textsuperscript{107} p. 107 quotes The New Zealand Government) at all ages from five to adulthood are shorter and stockier than New Zealand whites.

It is evident that Negroes in West Africa, Uganda, South Africa and those born in the U.S.A. are at birth ahead of whites in skeletal ossification. However, at greater ages white children become the more advanced. The Seasonal Effect on the velocity of growth may be noted in most data. At all ages growth in height is faster in Spring and gain in weight greater in Autumn. The weight gain in Spring may be almost the equal of the Autumnal gain in optimal circumstances; while a small percentage of children actually lose weight in the Spring (presumably due to less favourable circumstances).
Psychological Disturbance and Growth Rate: The clearly controlled study of Widdowson (1951\textsuperscript{114}) led to the conclusion that "better is a dinner of herbs where love is, than a stalled ox and hatred therewith" (p. 1318). In the group of children concerned, height was less affected than weight, but of the same nature (p. 1317). Exercise: Tanner (1962\textsuperscript{107} p. 135) is of the opinion that no conclusions can be drawn from what data is available. However, in respect to the facial skeleton, the case history presented by Moss 1968\textsuperscript{89} (p. 97) indicates the essential contribution of function to mandibular growth and development. Isometric exercises to improve masseter and temporalis muscle contraction are advocated by Kuhn 1968\textsuperscript{70} (p. 341).

Socio-Economic Class and Rate of Growth: It is evident that children in the better favoured groups are always more advanced towards maturity. Girls reach menarche earlier, according to Tanner 1962\textsuperscript{107} (p. 139) and boys commence pubescence earlier. Clements, Davies-Thomas and Pickett 1953a\textsuperscript{24} (p. 1424) concluded that the permanent teeth tend to erupt earlier. Children of the 'upper classes' tend to be taller regardless of the number in the family, though they have less weight for their height (Tanner 1962\textsuperscript{107} p. 140). Hammond 1955\textsuperscript{54} (p. 208) decided there is "no social gradient in
body fat comparable with that in weight and height in school children". Tanner 1962\textsuperscript{107} (p. 140) suggests that in the less favoured groups there is lesser growth of the skeleton in length for its breadth; hence the relative linearity of 'better off' children. Proposed reasons for the socio-economic differential are nutrition, regular meals, sleep, exercise and the better organization that goes with a good home.

In the less well-off classes, Douglas and Blomfield 1958\textsuperscript{30} (p. 59) found children belonging to many-sib families to have less height at 4\frac{1}{2} years compared to their peers of one- or two-sib families. **Secular Trend:** Children are tending to grow quicker, reach adolescence at an earlier chronological age and finally attain a greater size as adults than those of 30 to 50 years ago. The increase is mainly of body size as a whole rather than proportions. This secular trend is of much greater effect than the differences between the socio-economic classes mentioned earlier, and those between geographical regions.

The difference between height and weight is well established by seven years of age when cross-sectional studies in 1938-9 and 1883 are compared (Tanner 1962\textsuperscript{107} p. 145). The advancement of the children in the former being up to 1\frac{1}{2} years. The velocity of height growth is greater in the pre-adolescent years of the 1938
group, they reached 'puberty' earlier and while their peak spurt of adolescence on an average occurred about 12 months earlier, the actual magnitude of the spurt is shown to be about the same as that for the 1883 group. Similarly, data for North American, British, Polish and German studies show the same secular trend as the Swedish children mentioned. The difference in size of children of 50 years ago and present day is due to acceleration of the maturation process and to the greater ultimate adult size attained. (Tanner 1962\textsuperscript{107} p. 149.) Just as menarche is occurring earlier, the menopause is occurring later, "suggesting that the pituitary is involved in the genesis of both trends". (ibid., p. 154)