THE IMPACT OF X-RAY CEPHALOMETRY ON ORTHODONTIC CONCEPTS.

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This thesis, as the title implies, is devoted largely to a review of a few of the very many cephalometrical studies which have appeared in the orthodontic literature of the United States. While I have covered a certain proportion of the articles published, there are many which are only summarised in the literature and others for which space has not been found for publication.

In fact in the quarter century since X-ray cephalometry originated it has grown to such an importance that most of the space in the journals is taken up with investigations using these methods. Indeed as the Editor of the American Journal of Orthodontics remarks, he could fill his publication for months ahead to the exclusion of any other subject matter if he accepted all the articles submitted to his journal.

X-ray cephalometry has had far reaching effects on orthodontic concepts in the fields of growth and development research, diagnosis and treatment planning cases. These influences which have changed the whole outlook of most orthodontists over the past year I will detail later.

As would be necessary in any critical review of orthodontic literature, I have endeavoured to report on a cross-section of articles on other sections of orthodontic teaching and I consider that the far reaching effects of the findings of various research men in cephalometric studies can be seen right throughout the various philosophies of orthodontic treatment.

Although much has been achieved in the past, there are opening up much broader avenues of research for the future and particularly so in the investigation of the dynamics of the occlusion. Studies in electromyography, joint functions and laminography all of which are consequential to cephalometry and must in the future furnish extremely valuable information to aid in the greater understanding of the etiology and treatment of malocclusion. The static concepts of orthodontia are fast disappearing, and the sooner the better, to be replaced
with a thorough knowledge of the occlusion of the teeth and the relation of dento-facial structures as a living and moving system of variables. The days when the prime clue to malocclusion was a pair of plaster models representing upper and lower teeth must be forgotten.

The great individual variations in skeletal and muscular structures between patients throws grave doubts on whether the time-honoured classification of E.H. Angle is of any further use even in the absence of anything to replace it. Indeed I am of the opinion that the classification or attempted classification of all malocclusions into about six main arbitrary divisions and their treatment according to the division in which they fall should be abandoned altogether. Angle's classification seems to be useful only to describe one peculiarity of the particular malocclusion.

From the multitude of cephalometric investigations we have been able to define many other factors which enter the make-up of malocclusion. The molar relationship is the evidence of some of these factors but there are many others that much be taken into account in thoroughly analysing a case. While Angle's and other classifications relying mainly on dental relationships were certainly a great advance out of the dark ages fifty years ago, they must now be considered as out of date. I feel that this is the general opinion of the most thoughtful of American Orthodontists although out of difference for one to whom so much is owed they do not put it so bluntly.

Rather than try and take the easy way and place the malocclusion into one of about six classifications, Brodie, Wylie, Fischer and others insist that each case must be taken individually and all the factors entering into the malocclusion carefully weighed. That the basic requirements for an analytical dissection of this nature must be accurate head films is shown by the methods of Downs, Wylie, Graber and others. A consideration of what data can be obtained using one or more of these methods for the analysis of malocclusion and the prognosis of the case must make one who was in practice
thirty years ago shudder at the flimsy evidence then available on which to base treatment plans. Cephalometry therefore has earned a prime place in treatment but there are dangerous trends in its use which many investigators have followed.

**THE INTRODUCTION OF X-RAY CEPHALOMETRY**

I consider that Simon was the first man to try and relate the dental structures to the planes of the head and deserves great credit instead of the very cold reception which his work received in America. In fact Hellman went to great pains to disprove Simon's main finding. The fact remains however that the system of "gnathostatics" originated by Simon was a great advance on any other methods at that time and although a rather cumbersome technique must be given the credit of being the first step in relating the teeth to facial and cranial planes. The next step was the introduction of the standard lateral head X-ray by Broadbent in 1931 and also Horfrath in the same year. The method of orientation of the head varied in the methods of these two men and since Broadbent's was found to be more reliable, his method has remained virtually unaltered since its introduction twenty-five years ago.

It is rather remarkable and a great credit to Broadbent that his methods have not been improved on up till the present time and it is my opinion that many of the more recent researches would be much more beneficial if they were to follow the simplified methods and concise presentation of facts shown in Broadbent's three papers.

The paper on Bolton Standards and Technique in Orthodontic Practice in which he traces the results of treatment in twins only one of whom has a favourable growth trend shows how valuable this procedure can be in following changes in growth and treatment. The presentation of these articles I consider classics of their type and although favourable material such as twins is not all easy to come by a serial study of this type gives much more reliable data than studies in which the subject matter, although more numerous, is badly chosen.
Broadbent uncovered much developmental and growth data pertaining to the face, jaws and teeth. Brodie continued the work on growth and in a serial investigation followed growth in the child from the third month to the eighth year of life. This work was later extended and Brodie and his associates are responsible for a great deal of cephalometric study most of the material for which has come from the files accumulated in Broadbent's Bolton study. The details of the Bolton Broadbent cephalometer well known and this machine instituted a radiographic approach eliminating the inaccuracies of previous anthropometric work. However the main disadvantage of this machine was its costs (6,000 dollars) which virtually limited its use to wealthy research laboratories. Broadbent's work however soon awakened in the minds of orthodontists an awareness of the potentialities of this method of study and it was not long before simpler and less expensive methods of producing the standard lateral X-ray were devised. Modifications in the positioning of the head were introduced and also the use of aluminium filters enable the soft tissues to be portrayed. Particularly is this applicable to the soft tissues of the facial profile and the larynx. Oral tissues may be shown better by painting them with a solution of tantalum powder.

**REGISTRATION METHODS**

Broadbent's main plane of reference was the Nasion-Bolton plane and the sella point and the registration point on the perpendicular from sella to N-B plane, serve their purpose well in Broadbent's investigations. Brodie's Nasion-sella line seems to be the most useful and stable line of reference. This line varies little during growth and particularly from the age of twelve years onwards, according to Bjork, its displacement is very slight. This plane has become the basis of nearly all cephalometric studies.

The Frankfort horizontal plane which was taken from the field of craniometry is the subject of much argument as to its suitability as a reference plane. Bjork contends that
the skeletal landmarks necessary for its construction cannot be accurately identified on X-rays and considers it to be of no practical value in the analysis of X-ray profiles. Downs however uses this plane as the basis for his diagnosis studies and seems quite convinced from his researches of its stability and suitability. As it is virtually a facial plane I think it would not be quite suitable as a reference plane for serial growth studies over a long period, however in the later age groups to which the Downs' analysis would be applied, the Frankfort horizontal plane should be fairly well stabilised.

Apart from these two planes a multitude of anatomical points and landmarks have been defined and are too numerous to detail here.

However in this field of cephalometrical research there are a few trends which in my opinion tend to detract from the usefulness of some research work into which much effort has gone.

The first of these is the tendency of many writers when seeking to produce some original research to seek our some system of anatomical points and planes which has not been used before. This is the original part of the research but much of value is lost because the new reference planes chosen and relations derived do not throw any further light on the findings of previous studies.

These men would be serving orthodontic purposes better if they were to investigate relations of parts using a system of exact landmarks which will permit a searching analysis of the morphology of the skeletal parts involved.

We thus seem to have many articles appearing in which even basic reference points and planes are different. The results of these researches cannot be critically compared and thus lose much of their practical value.

In most sciences the research of today should be applied to practice tomorrow but I consider that the clinical orthodontist would be hard put to it to glean much information from some of these cephalometric studies let alone apply them in
his practice. Therefore a standardisation of cephalometric landmarks would be a great step in keeping cephalometrical research within the bounds of usefulness and within the understanding of the man who is not a research scientist or a statistician.

Attempts to relate points in totally different sagittal planes of the head would affect much of the data put forward by some writers. This factor of the width of the facial structures has been disregarded in many investigations.

The adequate study of transverse growth of the cranium is not possible from X-ray cephalometrics but this difficulty may be overcome by resorting to laminography and direct measurements of the width of the face and the occlusion in the coronal plane should be possible in future studies.

GROWTH AND DEVELOPMENT

Brodie work is of much importance in that it showed that the pattern of skeletal structures is due to hereditary factors and becomes evident at a very early age. This pattern is not changed during growth but its full development may be retarded by pathological or environmental factors.

The unfolding of the developmental pattern and strong adherence to inherited predetermination has been shown many times in the work of Broadbent and Brodie.

Growth cannot be stimulated and miracles cannot be achieved in treatment with an adverse growth pattern. Moreover once lost through some cause is lost forever and cannot be regained.

X-ray cephalometry is particularly suitable for longitudinal growth studies and valuable contributions will be forthcoming from this type of study. There has been shown to be a very great variation in individuals in facial development with age and particularly have these changes been shown in the work of Bjork and Brodie.

Cross-sectional studies do not provide any indication of the great individual variations involved and which are all lumped together in the production of mean values.
The majority of studies are based on a number of cases which is too small numerically for the purpose of providing information about the interdependence of variations and when this material is treated in a cross-sectional manner much of the essential information is missed.

The development of the teeth, their eruption and subsequent progress to occlusion is illustrated very well by the lateral head plate and Broadbent has covered this subject very thoroughly in his monograph on the development of the occlusion.

Cephalometry relates the evidence obtained clinically and by intra-oral X-rays to the whole facial area. Growth changes in the facial pattern as shown in the X-ray can only be thoroughly understood if the growth mechanism of the various parts is known. Therefore X-ray information from humans and animals must be correlated with experimental studies on animals carried out by vital-staining techniques.

Affects on growth in cases of hypothyroidism, obesity, pituitary dwarfism have been studied cephalometrically. Discrepancies in growth in cleft palate cases have been investigated by several writers and their findings have changed the treatment of these cases.

**DENTO-FACIAL MORPHOLOGY**

Cephalometric X-ray investigations into the facial pattern have been carried out by many workers who have endeavoured by these methods to provide a basis for clinical analysis in order to point out dental abnormalities and predict treatment aims and limitations. A full realisation of the complexity and number of factors entering into the facial structure has led to the abandonment of the concept of ideal or normal facial patterns or occlusion as a rigid criterion.

Bjork is responsible for a tremendous amount of research on the morphology of the skull and has endeavoured to relate the changes in the pattern of the bony profile of the face to the shape of the cranial base. His work has been carried on in subjects of different age groups and races with widely varying facial characteristics.
Results of his studies on prognathism and related subjects of overbite and overjet and contributed much valuable data to orthodontic learning. His system of analysis while excellent for the purpose of his studies does not lend itself to more clinical investigations as well as some other systems. Research work carried out under the supervision of Dr. A. C. Brodie at the University of Illinois provided a mass of data useful in the understanding of variation of facial structure. The main value of these investigations lay in the fact that they were directed along a definite line of research by a man of such great ability as Brodie. Deductions from the findings were spoilt to a certain extent by the following failings.

1. As the cases under study were for the most part picked out with reference to various classes of malocclusion according to Angle, criticism can be levelled in that the material is hand picked and depends solely on the judgement of the investigator. Bad sampling would adversely affect the accuracies of the deductions. This is particularly noticeable in Class II cases. Benson avoided this error by reclassifying some cases on the basis of treatment results.

2. In some of these studies inadequate amounts of material we use considering the deductions which were made from the data. When a greater amount of material is used extremes will vary more greatly and the errors of investigator will be less noticeable in the results.

3. Particularly is the detrimental factor of limited sampling noticeable when statistics have been used. The fallacy of relying on inadequate statistical data is shown for instance in two studies in which the same data is analysed by different men and varying deductions made statistically.
In the last ten years cephalometrics has been used to try and establish positive diagnostic criteria in the form of normal ranges of values about various standard mean measurements.

The work of Margolis in producing his Maxillo-facial Triangle was an important step and these measurements indicate certain discrepancies in pattern.

The work of Tweed carried out on photographs and models put forward the concept of the incisor occlusal plane relation and the erectness of the mandibular incisors to the mandibular plane.

Wylie in 1947 produced his system of linear measurements to assess anteroposterior dysplasia and to attempt to single out the area responsible for discrepancies in development. One disadvantage of Wylie's work is that slanting line measurements were compared to horizontal line measurements.

In 1948 Downs introduced the most comprehensive system of analysis of facial variations yet devised, and this system seems to be in general use today in many countries after being extensively tried out in research laboratories. The Downs' analysis represents the most thorough and objective method yet advanced of elucidating the large number of factors which lie behind any malocclusion and how much each contributes to the condition.

Graber has presented an excellent diagnostic analysis somewhat similar to that of Downs but simpler and more suitable for use in practice, particularly in explanations to parents of patients.

Steiner presents an interesting system of cephalometric appraisal which uses certain relations derived from previous works but which in its simplicity should be ideal in orthodontic practice.

All these systems of cephalometric analysis involve an attempt to reduce anatomical and functional relations to angles and linear distances the degree of accuracy of
which must be diminished when it is realised that they are changing a three dimensional system of parts and portraying it in a two dimensional diagram. This is particularly so in linear measurements which may be more misleading than angular values.

Any normal standard must be sufficiently broad to encompass all reasonable variations. Group standards should be used only as a guide in treatment and the goal must be an individualistic norm.

THE EFFECT OF CEPHALOMETRICS ON FUNCTIONAL ANALYSIS.

The work of Thompson on the rest position of the mandible opened many new avenues in research in orthodontics and his findings have also been of value in other branches of dental science. Thompson studied sagittal difference in rest position, in relation to occlusal position, as a displacement of the mandible. Thompson's articles stimulated researches on the function of the temporo-mandibular joint both in normal and pathological function by means of X-ray cephalometry and laminagraphy.

Thompson and Brodie made a study of freeway space and applications of their findings have been particularly valuable in treatment of cleft palate cases in which there has been an arrest in maxillary growth.

Changes in paths in mandibular closure due to treatment have been investigated.

Subsequent to research of the functioning of the temporo-mandibular joint electromyographic studies have been carried out on the muscles involved and have yielded very valuable information on the interaction of these muscles.

By the use of X-rays the position and functions of other soft tissues can be gauged. These include the actions of tongue and lip muscles in perverted swallowing habits and impediments to correct speech. The position and pathological state of adenoid tissue can also be described.
The last twenty five years have seen a gradual growth in
the awareness among orthodontists of a new philosophy that
all things desirable in treatment are not possible even
to the best informed and most skilled operators and that
all appliances have their strict limitations. A realisation is essential that all patients present different
potentialities with the respect to the attainment of results
in orthodontic treatment.

This realisation was hastened by the findings of Brodie
and his associates in 1938 on the limitations of treatment.

1. The orthodontist is able to move teeth and to do
   so without markedly disturbing their axial inclinations. However tipping is the predominating
   movement unless great care is exercised to prevent it.

2. In all cases in which intermaxillary elastics were
   worn there was a disturbance of the occlusal plane.
   In Class II treatment plane was tipped down in
   front. In Class III treatment the reverse took
   place. In both cases there was a tendency for the
   plane to return to its original relations following
   treatment but this tendency diminished with age.

3. In a number of cases of all classes part of the
   result obtained was shown to be contributed by
   a change in the position of the mandible.

4. Actual bone changes accompanying orthodontic
   management were shown to be restricted to the
   alveolar process. The ability of this structure
   to adapt itself to changes in the position of
   the teeth is extremely great.

5. Changes subsequent to treatment were found to be
   limited to shiftings in the occlusal plane and
   to changes in axial positions of teeth in adult
   cases.
In growing children there were in addition the typical changes expected in growth.

6. There seemed to be a definite correlation between success in treatment and growth. These findings from cephalometric studies of treatment results virtually sounded the death knell of the functional concept of Angle and the belief in expansion of the arches as a major part of treatment. The use of X-ray before, after and during treatment clarifies the possibilities and limitations of appliance therapy.

I would attribute the drift away from the use of intermaxillary anchorage in the treatment of Class II Division I cases to a more thorough understanding of the causes of this malocclusion by the use of cephalometry and also by a realisation of the disastrous effects on the mandibular anchorage arch in many cases by the elastic forces used. These changes were not evident and could not be accurately measured before the inception of the lateral head X-ray. The drift from intermaxillary anchorage to occipital anchorage is most noticeable from a perusal of the number of articles devoted to its technique in the Journals.

The return to earlier mixed dentition treatment by many operators I would attribute to a better insight and recognition of the beginning of incipient malocclusion seen, and only able to be seen, in the cephalometric X-ray. Donovan has written an excellent article on the recognition of growth trends during treatment and his results have shown that we can only expect favourable results if the patient shows favourable growth trends.

**CONCLUSION**

1. Through the advances of cephalometry particularly as applied to clinical diagnosis, diagnostic criteria which previously was unseen or could only be recognised by orthodontist with years of clinical experience behind him is readily
accessible to all interested enough to pursue this form of case analysis.

2. This work no longer necessitates the use of expensive research type equipment and head orientors can be obtained within the reach of the ordinary practitioner and standard dental X-ray equipment can be used.

3. Anatomical landmarks, planes and measuring points must be kept standardised and simple and must be easily recognisable from the films.

4. Complicated systems of analysis and intricate statistical methods which cannot be understood by the ordinary practitioner should be avoided.

5. Cephalometry is not a substitute for plaster casts, intra-oral X-rays, photographs or most important of clinical examination of the patient. However it will correlate much of the information presented by the foregoing and much more accurately.

6. Angle's classification became a bible for the lazy to lean on and plan their treatment and it has been proved unsatisfactory. We must beware of treating cephalometrics in the same way. It must not be used as a substitute for our own thinking and working out each case analysis and treatment plan individually.

7. Finally I'd like to quote Bjork, one of the most eminent contributors to the study of cephalometry and Failing who cautioned the orthodontist who would rely on cephalometrics thus:"

"The value of biometrical methods in clinical diagnosis depends entirely on the user's appreciation of the limitations inherent in the method. Cephalometric methods of analysis, especially growth analysis, can be extremely valuable but presupposed a thorough knowledge of normal
and anomalous growth and development and how to interpret biometrical methods. Failing this, such methods may prove difficult to understand and may even be misleading."
Bone, which is the structure of the human body and particularly of the skull of most concern to the orthodontist, has been probably the most neglected in all orthodontic literature.

In their general textbook of bone biology, Weinman and Sicher present an excellent treatise on the normal structure and growth of bone as a tissue and bones as organs of the body as well as dealing extensively with the various pathological conditions to which this tissue is susceptible.

Bone tissue consists of two permanent elements - specialised cells and intercellular substance.

Permanent cells are known as osteocytes and the intercellular substance is composed of fibrils and a calcified cementing substance.

The two transient elements are the osteoblasts which are present when bone is being actually formed and osteoclasts which are present when resorption is taking place.

Bone resorption and bone deposition are vital factors in the growth period of the skeleton.

Removal of bone entails a simultaneous disappearance of the organic and inorganic components of ground substance.

Weinman & Sicher state categorically that the occurrence of decalcification of living bone has never been proved and that it seems certain that it does not take place.

There are two types of bone which are macroscopically distinguishable:—

(a) Spongy bone consists of bars, plates, and tubules of bone of varying thickness and length which form a network in the three dimensions of space.

(b) Compact bone consists of lamellae arranged in cylindrical systems and each system consists of varying number of concentric lamellae grouped around a narrow axial channel which contains blood vessels.
A system of these lamellae is known as an Haversian system.

Between the packed Haversian systems the irregular spaces are occupied by the interstitial lamellae.

According to Weinman and Sicher, bone formation always occurs in every instance by differentiation of connective tissues.

Osteoid tissue is first formed, then this organic substance is calcified.

Spongy bone is developed primarily and then compact bone is formed by the continued apposition of more and more trabeculae forming Haversian systems.

**BONES.**

A bone as an element of the skeleton consists of the following different tissues.

**PERIOSTEUM:** is a layer of dense connective tissues which covers the outside of the bone and varies in thickness in different areas.

Muscles are attached to the bone itself or the periosteum. Tendons are always attached to the bony surface. Where muscles or tendons are attached to the bone the connective tissue which replaces the periosteum in these areas extend into the bone as Sharpey’s fibres.

**BONE MARROW.**

In the foetus and infant the marrow spaces are filled with red haemopoietic bone marrow. This red marrow is gradually replaced in early life by yellow or fatty marrow except in the flat bones of the skull, vertebrae, ribs and sternum where the red marrow continues to form red blood cells. The marrow is lined by the endosteum.

**NERVES.**

The nerve supply to the periosteum is the type which accounts for the high sensitivity of the periosteum. Other nerves enter the bone through the nutrient canal and are distributed throughout the bone.
BLOOD SUPPLY OF BONES

Some arteries enter bone and supply bone marrow while others supply the compact layers from the periosteum.

(a) Longitudinal section through long bone
(b) Cross-section long bone through diaphysis
(c) Longitudinal section of Phalanx of fetus of five months

DEVELOPMENT OF BONES

There are three types of bone development and these are:

1. Those which replace a preformed cartilaginous shape.
2. Bones which develop in connective tissue and are not preformed in cartilage.
3. Membranous bones which include the clavicle and mandible and in which secondary cartilage develops at a later stage.

1. ENDOCHONDRAI DEVELOPMENT of bones is typified in the formation of the long bones of the extremities. The shaft of a long bone grows in thickness by apposition of two layers of bone upon the periosteal surfaces of the shaft. This is accompanied by an internal resorption of bone. Longitudinal growth takes place at the plates of hyaline cartilage which separates the epiphysis from the diaphysis.
This cartilage grows and elongates bone and then is replaced by bone.

2. **MEMBRANOUS DEVELOPMENT OF BONE** This type of bone in the skull grows by two means:

1. By apposition on the free surface with corresponding resorption.

2. Sutural growth.

Although some authors consider the apposition of bone on free surfaces, the main avenue of growth and sutural apposition as a secondary filling in, Weinman and Sicher are opposed to this view and consider that the skull as a whole enlarges by sutural connective tissue proliferation and cartilage growth in the synchondroses. They state that expansion of the skull occurs by sutural growth and cartilagenous growth and apposition and resorption are responsible for the flattening of the curves which must take place as the curved bones expand.

3. **MEMBRANOUS BONES WITH SECONDARY CARTILAGENOUS GROWTH CENTRES.** This type of bone development can best be exemplified in the mandible in which several cartilagenous centres develop, the most important being that cartilage in the condyloid process.

   (a) The mandible develops as a membranous bone, lateral to and at some distance from Meckel's cartilage.

   (b) In the third month of intrauterine life the connective tissue covering the bony condyloid process differentiates into cartilage. Cartilage however develops only in the deepest layers of the connective tissue and does not reach the articular surface. Thus we have a cartilagenous cap covered by dense layer of fibrous tissue.
Therefore the condylar bone grows not only

1. By interstitial proliferation of the cartilage but also

2. By apposition of bone from the deepest layer of the fibrous covering.

In this growth centre we have an entirely unique set of growth conditions to those existing in the long bones and in the flat bones of the skull. This difference would account for the different behaviour of the mandible to that of the bones in general bodily disturbances of growth.

TO SUMMARISE

A. The Cranium is dependent for its enlargement
   (a) On cartilagenous growth as seen for example in the sphen-o-occipital synchondrosis.
   (b) On proliferation of connective tissue as seen in the sutures.
   (c) On surface apposition of bone in many areas. Endochondral ossification and sutural apposition of bone are secondary.

B. The mandible is comparable with a long bone because cartilagenous growth in its condyle and appositional growth of bone in other areas combine in its enlargement.

If cartilagenous growth predominates a tall slender individual should have a long mandible with a high narrow ramus and if appositional growth predominates over cartilagenous growth we should expect to see a short stocky individual with short mandible, low and wide ramus and a short face.

Bone being primarily a complex of calcium, phosphorous, carbonate and protein these are various mechanisms apart from the osteoblasts essential in the final production of well calcified bone according to Werner.
1. An optimal supply of calcium, phosphorous and of protein precursors must be available.
2. Glucose metabolism must be normal
3. PH of the blood and tissues and hormonal environment must be within normal limits.
4. Ingestion and absorption of adequate amounts of necessary constituents is essential.
5. Vitamin D is necessary for proper absorption of calcium and phosphorous from the gut.
6. Pathological conditions such as diabetes mellitus affect bone metabolism.
7. Secretions of endocrine glands are of prime importance in bone metabolism.
   (a) Adrenal glands
   (b) Gonads and ovaries
   (c) Thyroid gland
   (d) Parathyroid glands
   (e) Pituitary gland.

All these factors must function in harmony for correct bone metabolism and there must be an absence of diseases of bone, the pathology of which affects this tissue in different ways.

DEFINITION OF GROWTH AND DEVELOPMENT.

A. GROWTH.

Salzmann "Growth refers to an increase in cell units and is recognizable in the enlarged size or bulk of the body which takes place between birth and maturity."

Although growth takes place by progressive increments from conception to about the age of twenty years, growth centres vary in their periods of activity and some grow much more actively than others.

Hooten describes the "Rhythm of Growth" as follows:

"Human growth is not a steady and uniform process of accretion in which all parts of the body enlarge at the same time and the increment of one year is equal to that of the preceding or succeeding years. Growth takes place by fits and starts."
There is, however a certain method in this irregularity, such that a growth "rhythm" may be recognised."

From birth to 5 to 6 years in both sexes rapid growth takes place and particularly in first 2 years. Slow increase to 10 to 12 years in boys and 10 years in girls. Then comes the rapid growth of adolescence terminating in boys 16 to 18 years and in girls 14 to 16 years. Final period of slow growth terminates in females between 18th and 20th years and in males about 25th year.

These figures show a great individual and a considerable group variation in inception, intensity and duration of the various phases of the rhythm of growth.

Functional, environmental, nutritional and many other circumstantial factors may vary this pattern of growth.

B. DEVELOPMENT

Salzmann "Development relates to cell division, growth, differentiation, and maturation and may be defined as the sequence of changes from cell fertilisation to maturity."

Strang defines "development as the structural changes and adjustments of parts that take place in order to maintain correlation, with advancement in age and the approach of maturity."

Wylie quotes the White House Conference of 1931 which defined - "Growth as increase in size."

"Development as progress toward maturity."

He summarises the basic approaches to a study of growth and development under two headings:-

1. CROSS SECTIONAL approach in which a great number of subjects at a certain stage are compared with other groups at succeeding stages, the means being used for comparisons.

2. LONGITUDINAL or serial or vertical approach which may take a long time but in which the same group is followed through succeeding stages. Broadbent's serial X-rays of about 4,000 Cleveland children is instance of this type of study.
We have four methods of growth study available.

1. **Anthropometry** in which measurements are made from soft tissue landmarks and which method is rather inaccurate because of the wide variations in soft tissue coverings.

2. **Osteometry** is concerned with the measurement of skeletal remains of adults and children. As supplies of skeletons are limited, these methods have their limitations, but are useful in the study of the philogenetic development of the hard structures of the body.

As children whose skeletons are available for study have probably died from some pathological cause the measurements taken from them would not necessarily be applicable to the normal healthy child.

3. **Standardised Roentgenography**

   The standardised X-ray technique which was introduced by Broadbent gives us completely controlled pictures of growth and every set of films over a series is exactly comparable with these preceding and following it.

   Broadbent's contributions and those of the research workers who followed him will be discussed later in this thesis.

   The accurately orientated head film shows changes in the overall pattern of growth but cannot tell us where growth takes place except in locations where the growth site differs from the remainder of the bone.

   There are two such sites of cartilaginous synchondrosis in the skull, the sphenoid junction and the sphenoid ethmoidal junction. **BUT IN THE FACE THERE IS NONE.**
Vital staining demonstrates the actual sites of growth in the face and for research on these lines we are indebted to HUNTER, BRASH, and MASSLER.

These studies have shown that in the early years of post-natal life bone is deposited on all facial surfaces, but that later only localised sites contributed to the growth of the cranium and face among which are:

1. Sutural borders of flat bones
2. Posterior border of the mandible
3. The front-nasal process and the tuberosity of the maxilla.
4. Inferior surface of the hard palate and the trans-palatal suture.
5. Head of the mandibular condyle and the semi-lunar notch.
6. Alveolar process about the teeth.
A concomitant process of resorption holds bulk in check and maintains proportion.

CARPAL INDEX

For the sake of convenience and economy the hand, the wrist and the distal epiphyses of the radius and ulna, which altogether present a large number of secondary centres of ossification, some of which are present at birth and all of which can be represented on one X-ray are selected as regions to determine the stage of skeletal maturation of the individual.

The approximate skeletal age of a child may be determined by the number of centres of ossification and the degree of ossification of these bones.
Ossification centers of the hand, showing average time of appearance and fusion of ossification centers in the hands of boys and girls.

The beginning of work on the growth of bone may be attributed to Belchier (1736) who found that madder root stained bone red.

Duhammel went further and showed:
1. That only part of the bone stained red
2. That bone of young animals stained more deeply than old
3. Only new bone took the dye

In 1754 Hunter commenced his work on the mandible and for the first 10 years he apparently relied on observation for his findings.

He pointed out:
1. Destruction of alveolar bone following extraction.
3. Molars both deciduous and permanent all seem to erupt and bear the same relation to the ramus.

In 1764 Hunter using Duhammel's staining methods proved his assumptions and also
4. That addition was as characteristic of bone as resorption.
5. That there was no interstitial expansion of bone.
In 1771 Hunter described ideal occlusion and the growth of the mandible. His work on the growth of the mandible which has not been contradicted up until the present may be summed up by saying that the height was mainly increased by deposition at the alveolar border, and length was gained by the deposition at the posterior border of the ramus and resorption at the anterior border of the ramus above the alveolar border.

As early as 1924 Brash emphasised that disturbances of growth although they may be most noticeable in the arrangement of the teeth and alveolar bone are common to the whole of the face and to a lesser extent the whole skull.

**RATES OF GROWTH**

There is an uninterrupted steady increase in the dimensions of the face, this increase being greater relative to the increase in the growth of the rest of the head.

**THE MODE OF PRODUCTION OF THE NORMAL FORM**

The mode of growth was studied by Brash in the mandible of the pig. He quotes Hunter who 152 years ago in 1803 described the growth of the mandible thus:

"The jaw still increases in all points till twelve months after birth, when the bodies of all the six teeth are pretty well formed, but it never after increases in length between the symphysis and the 6th tooth; and from this time too, the alveolar process, which makes the anterior part of the arches of both jaws, never becomes a section of a larger circle, whence the lower part of a child's face is flatter or not so projecting forward as in the adult.

After this time the jaws lengthen only at their posterior ends so that the 6th tooth, which was under the coronoid process in the lower jaw, and in the tubercles of the upper jaw of the foetus is at last, viz. in the eighth or ninth year placed before these parts; then the 7th tooth appears in the place which the sixth occupied, with respect to the coronoid process and tubercle; and about the 12th or 14th year the eighth tooth is situated where the seventh was placed."
At the age of eighteen or twenty, the eighth tooth is found before the coronoid process in the lower jaw and under or somewhat before the tubercle in the upper jaw, which tubercle is no more than a succession of sockets for the teeth till they are completely formed."

**THE GROWTH OF THE MANDIBLE IN THE PIG**

Brash in his madder feeding experiments on the mandible of the pig showed a growth of the mandible by extension of its border in all directions except along the anterior border of the coronoid process.

**MODE OF GROWTH OF THE UPPER JAWS.**

Surface apposition with accompanying modelling resorption takes place as in the mandible but the most important type of growth is sutural growth. Thus in the skull we have the growth in the various synchondroses, very active sutural growth between the membranous bones and surface apposition beneath the periosseum with its concomitant resorption in such places as the Maxillary sinuses. Brash also traced the growth sites by madder staining in the bones of the skull of the pig and applied his results to the human skull.

In a general survey of the many factors directing and influencing growth, Krogman makes a statement of some comfort to orthodontists. "Growth and development operate with the orthodontist and not against him."

He states that growth is governed by two genetic factors, one of which presides over general size and the other over specific proportion.

There is a definite human pattern of growth in which periodic rhythms are eventually all integrated into an ultimate proportion.

In the body there are four modes of growth:—lymphoid, neural, general body, and genital and each has its own growth curve and pattern of growth.
Constitutional and endocrine factors influence pattern and type. Since dental development and facial growth follow the same biological growth laws as the rest of the body a thorough knowledge of growth theory is valuable tool in orthodontic practice.

DEVELOPMENT AND GROWTH OF THE HEAD

A. Growth of the Cranium
   1. The vault
   2. The base

B. Growth of the face
   1. Upper jaw
   2. The mandible

BONES OF THE SKULL

There are twenty two bones in the skull of which only the mandible is moveable. Eight bones form the cranium, and fourteen the face. The bones of the cranium include the frontal, 2 parietals, the occipital, squamous portions of the two temporal bones, the greater wings of the sphenoid and the ethmoid.

The bones of the face include 2 maxilla, 2 palatals, 2 malar 2 zygomatic, 2 lacrimal, 2 nasal, and 2 inferior nasal conchae; and also the vomer bone and the mandible.

The "law of developmental direction" holds that the more proximal dimensions of the body complete successively a greater percentage of their ultimate size than the more distal.

Thus we see in the skull the cranium is always ahead of the facial skeleton and particularly the mandible as regards growth and development. The growth of the skull is most complex in a phylogenetic and ontogenetic and in a functional sense.

The cranium or brain case is inseparably and immovably fixed to the masticatory facial skeleton with different surfaces of the same bones forming integral parts of each.
The growth pattern becomes complex when it is realised that the growth and development of the cranium or brain case is entirely dependent on the demands of the brain for expansion whereas the growth of the masticatory part of the face is dependent on muscular influences, dentition and growth of the tongue and certain environmental factors.

Not only do the two parts of the skull follow different paths of development but the timing of their growth rates shows a great variation.

I think the best method to unravel this complex development is to commence with the study of the growth of the cranium vault and then follow the development through the base of the cranium to the facial skeleton of the upper face and mandible.

A. 1. **GROWTH OF THE CRANIAL VAULT**

X-rays of the same child taken at regular intervals show the growth of the brain capsule or inner plates of the bones of the skull to be concentric when the sella turcica is used as a central reference point.

Concentric growth of the cranium vault. Superimposed outlines of the skull from cranio-metric roentgenograms of the individual at different ages.

A. From three months to seven years of age.
B. From six months to eight years of age.

The mechanism of the enlargement of the cranium vault is by connective tissue growth in the sutures. Ossification of the proliferation connective tissues is secondary and in rapid growth periods, lags behind the proliferation of connective tissue.
Although some authors have written to the contrary, Weinman and Sicher are quite adamant that the apposition of bone must be considered as confined to individual bones for modelling purposes mainly. This seems reasonable as the rate of growth of the cranium especially in the first two years is so rapid that expansion by sutural growth could only account for the development. As sutural growth expands the cranium, changes in the curvature of the individual bones are necessary and significant. This is the role of the appositional bone growth with its concomitant modelling resorption. Flattening is accomplished by resorption on the inner surface in the areas near the sutural borders, plus apposition in the central areas of the inner surface. Apposition of bone on the outer surface of the bones thickens the bones and is especially active near the borders of the sutures. In several areas thickening of the cranial walls is not uniform and the outer plate diverges from the inner plate. These areas are in the nuchal areas, the external occipital protruberance developing particularly under muscular influences. In the supra-orbital and mastoid areas the frontal sinus and mastoid process for muscle attachment is formed.

2. GROWTH OF THE CRANIAL BASE

The mechanism of growth of the cranial base is principally dependent on cartilagenous growth at the spheno-occipital, the spheno-ethmoidal synchondroses. The intersphenoideal synchondrosis disappears soon after birth. The cartilagenous plate between the occipital and sphenoid bones is responsible for most of the antero-posterior increase in dimension and this cartilage is not replaced by bone until sometime: between the 16th and 20th year. Suture growth between the petrous portion of the temporal bone and the lateral portion of the occipital bone is manifested in an antero-posterior and a lateral direction since this suture is placed obliquely.
The great wings of the sphenoid in its sutural junctions
with the squamous portions of the temporal and frontal
bones has a large influence in the increase of antero-
posterior dimensions of the floor and sides of the cranium.
This growth of the base of the cranium is predominately
forward in relation to the position of the foramen magnum
and thus the vertebral column.
The more rapid growth of the cranium in the early years
of life seems to have virtually carried the facial struct-
ures forward.
Then ensues, the quickening of the rate of growth of the
facial skeleton and a slowing down in cranial growth.
At the age of 10 years the cranium has developed to 90% of its mature size but the facial structures are then
entering upon a phase of rapid growth and development.

B. GROWTH OF FACE

Growth development of the facial parts of the skull is the
result of growth of the facial bones, aided by growth of
the cranium and the base of the skull.
The inherent growth pattern of the face is influenced by
function, growth of the sinuses, development, form and
position of the teeth, musculature, the tongue and count-
less environmental factors.
As growth of the face takes place over a much longer period
than growth of the cranium it is more susceptible to
environmental factors and consequently its growth shows
more variations.
During the growth period the facial skeleton increases in
all three dimensions of space, height, width and depth.
One important point is the regularity of growth and the
maintainance of the original pattern of the facial skeleton
and its relation to the skull.
Serial X-rays taken of the same child show, the plane of
the palate, the occlusal plane and the plane of the lower
mandibular border maintain a fairly constant angular relat-
on to the base of the skull and thus move through positions
parallel to each other.
The most important growth in the facial skeleton is the development of the maxilla and palatine bone. The main sites of growth are three sutures on each side.

1. Fronto - maxillary suture
2. Zygomatico - maxillary suture

Profile view of skull showing main sites of growth in maxilla and mandible. 1. Growth at the maxillary tuberosity at the pterygomaxillary junction. 2. Growth at the alveolar process. 3. Growth at the zygomaticomaxillary suture. 4. Growth of the maxillary process in the floor of the orbit. 5. Growth at the head of the mandibular condyle. 6. Growth at the posterior border of the ramus. 7. Growth at the alveolar process.

These three sutures are parallel to each other and are directed downward and posteriorly and hence by the growth that takes place in these sutures the maxillary complex is then shifted forward and downward.

This sutural growth accounts for the forward and downward positioning of the maxilla and its associated bones, but the increase in width presents a problem. The anterior part of the maxilla needs little widening and this is taken care of by a small amount of apposition and resorption. Some increase in width takes place in the median palatine suture.

The adjustment between maxillary width and the interpterygoid width is made possible by the downward divergence of the pterygoid process. As the maxilla grows downward so the pterygoid processes by bone apposition at free borders and
surfaces, and modelling resorption grow downward and outward so increasing the distance between their lower ends. There is intensive deposition of bone at the free borders of the alveolar process. This not only increases the height of the face but is necessary for the accommodation of the teeth especially the permanent dentition.

2. GROWTH OF THE MANDIBLE

The mandible has its origin in the first branchial arch. The mandible develops as a membrane bone lateral to and some distance from Meckel's cartilage. Secondary centres of cartilage differentiate in the mandible and form important areas of growth. The mandible is originally formed in two halves which are joined at the symphysis by fibrocartilage and which join and fuse at about the 6th month of intra-uterine life. During the first year of life the mandible virtually becomes one bone.

Secondary cartilagenous centres of growth form at the condylar process and at the mandibular angle but these disappear before birth.

The cartilagenous centre in the condyle of the mandible persists as the main centre of growth. The mechanism of growth at this centre has been described previously and is unique and differs widely from any other growth process in the skull.

Growth at this centre causes an increase of the ramus in height and also in the overall length of the mandible. Condylar growth has no effect on the length of the body of the mandible or on the antero-posterior dimension of the ramus. Appositional growth along the posterior border of the ramus adjusts the width of the ramus and the length of the body to the growing length of the ramus. Appositional growth at the tip and posterior border of the coronoid process keeps pace with growth of the condyle. Resorption at the anterior borders of the coronoid process and ramus keeps the antero-posterior dimension of the ramus in proportion and at the same time performs the very important function of increasing the space for the erupting molars.
at the alveolar margin.
Increase in height of the body of the mandible measured from
the lower border of the alveolar process is caused almost ex-
clusively by the apposition of bone at the free border of the
alveolar process. The increase is particularly marked at
the period of change from temporary to permanent dentition.
A small amount of deposition of bone takes place on the lower
border of the body of the mandible and a little modelling,
deposition in the region of the chin. Serial X-rays of the
growing mandible show that the gonial angle does not change
during growth but that the condylar angle decreases.
The proportions between the growth of the ramus height and
the growth of the overall length of the mandible determines
the size of the condylar angle. In the early periods when
the increase in length of the mandible predominates in order
to accommodate the molars the angle is more obtuse but later
as the teeth come into full eruption ramus height increases
and the condylar angle decreases.

X-RAY STUDY OF COMPARATIVE FACE GROWTH.
Broadbent established a means of using standardised serial
X-rays for children which gave more scientific and accurate
information on the growth patterns of the face and the devel-
oping dentition.
Broadbent employed a head positioning device with calibrated
ear posts which are inserted in the external ear openings.
The head is then orientated horizontally in the Frankfort
plane by a pointer applied at the left orbitale which is on
the same horizontal level as the ear posts. Two X-ray tubes
are employed and lateral and anteroposterior X-rays are taken
simultaneously. As references, Broadbent established the
Bolton-Nasion plane which runs from the Bolton point (the
highest point in the profile of the notches at the posterior
end of the condyles on the occipital bone) to the nasion.
A perpendicular is drawn from this plane to the centre of
the sella turcica and a point midway on this perpendicular
is termed the REGISTRATION POINT.
Serial lateral view X-rays taken over a period of years may be superimposed and related using the Bolton nasion references.

Broadbent used also as a reference the Frankfort horizontal plane and a perpendicular dropped from it at the orbitale.

Standardised lateral and frontal orthodiagraphic roentgenograms oriented for tracing and measuring dento-facial structures.

Tracing of Bolton roentgenograms shown above including some of the deciduous and permanent teeth and several of the anatomical landmarks. B - Bolton point. GN - Gnathion. GO - Gonion. M. - Median plane. NA - Nasion. OR - Orbitale. PO - Porion. R. - Registration point. ST - Sella turcica. Z - Zygomatic arch.
The development of this technique arose from the desire of Todd and Broadbent to find a mass of material on which to investigate growth trends which would give better data than skulls from museums.

Measurements of the soft tissue landmarks according to Simon's technique proved too unreliable to deduce hard tissue measurements. Broadbent saw the need for not only accurate lateral head X-rays, but a means of standardising a rigid technique so that the tracings from these X-rays could be compared to the very last detail.

1. The development of the craniostat was first requisite and served to firmly secure the head in relation to the X-ray film and the source of the X-rays so that identical pictures are produced.

2. Search for a stable line or point of reference was next undertaken since initial investigation had shown that neither the ear nor the eye point were stable enough to warrant their use as landmarks from which to measure changes in the teeth and jaws.

Chart of base planes with table of average dimensions of fifty males and fifty females showing standard deviation and coefficient of variability.
Research on skulls indicated that a stable area in the base of the skull was available and the points or landmarks of reference were relatively much more stable than any other points and more readily defined in the X-ray. The Bolton-Nasion plane and the Registration Point in the Sphenoidal area were selected as reference landmarks and this plane and point have proved to be reasonably stable. In the tracings the original Frankfort horizontal plane and the vertical orbital plane are depicted and in comparison of tracings made at various ages, accurate indication is given of the amount of growth and changes in the face not only in relation to these vertical and horizontal planes but also to the diagonal Bolton-Nasion plane.
In these tracings between one month and 2 years the changes in the various anatomical landmarks can be seen.

Tracings from lateral roentgenograms showing defective growth of the face during the first nine months. The points mark the position of the incisal edge of the deciduous central incisor for a comparison abnormal with normal growth. There is normal vertical growth but retarded anterior posterior development up to nine months.

Show tracings of a child in the same age range but with a record of ill health which has disrupted the orderly process of growth which was seen in the previous tracings.
Training of nine and fourteen and one half developmental years. Note relative stability of Bolton plane during the age range when most orthodontic cases are treated.

These tracings are representative of groups of 200 or more children in the period of change from the mixed to the permanent dentition.

Brodbent maintains that the children in the Bolton study who have a congenital absence of teeth show a reduction in size of the facial mass and an altered relation of the dental arches to their supporting bones in proportion to the number of teeth that are missing.

Tracing of fifteen years and one month and sixteen years and four months. Note the unchanged cranial base planes and continuation of facial growth to accommodate the third molars.
Shows growth predominating over development subsequent to the eruption of the twelve year molars.

Normal developmental growth of the face from Bolton study records.

Represents composite tracings from one month to adulthood.

In the chart of the normally developing face made by the comparison of the profile outlines of various ages, and registered in Bolton relation, we see the order and uniformity in which the face develops. We find the landmarks in the median sagittal plane moving forward and downward in a straight line. Exception to this is the nasion which moves forward and slightly upward. The Bolton point moves backward and downward. The anterior end of the palate, the incisor teeth, and the gnathion move forward and downward to a greater or lesser degree depending on their proximity to the cranial base.

Posterior end of the palate lies in the zone that divides the anterior from the posterior components of growth. Therefore landmarks in this zone move downward. The porion, and the gonion move downward and backward and since they are not in the median sagittal plane also move laterally.
Broadbent says that after the pattern of the face is established at the completion of the deciduous dentition, there is no marked change in the proportion of the face thereafter. There is more or less a proportionate increase in size.

Broadbent was able to prove that an assembly of dento-facial patterns of normal individuals of different ages expresses the same orderly and uniform pattern of growth that is revealed by the serial records in a longitudinal study of the same individual.

Brodie used the same standardised cephalometric X-rays as Broadbent and divided the head into its various component parts and studied the growth in each part from the 3rd month to the age of eight years.

Tracing of cephalometric X-ray of the head showing method of partitioning employed in study.

The head was divided into areas, cranial, nasal, maxillary and mandibular areas and the occlusal plane.

By using the angles and angular relationships formed by the lines bounding these various areas Brodie was able to more accurately trace growth patterns. By this method also he was able to compare growth in children even though their sizes were markedly different.
Brodie has shown that the incremental growth pattern of each area shows a marked parallelism as does the composite pattern of the whole skull.

Nasal floor, occlusal plane, and mandibular border all maintain constant angular relationship with the base of the skull.

Various divisions of the face maintain a constant proportionality, the nasal area for instance contributing 43% of the facial height.

The gonion angle does not change and the condyle growth centre plays an important role in the mandibular growth and is the last growth centre of the head to calcify.

A point of much interest he found is that the maxillary first permanent molars bear a constant relationship to the cranial base, and in this relation have a lower standard of deviation than any of the other facial measurements.

Once the individual growth pattern is established early in life there is a tendency for growth increments to follow a constantly parallel relationship to the original pattern while all anatomic points tend to progress along straight lines.

As the individual grows older the rate of growth diminishes.

In a study by Brodie of the growth of the mandible he uses the cephalometric data from Dr. Broadbent's collection and from the files of the Bolton Fund. While X-ray material is quite accurate for the study of rates and tendencies of growth, sites and modes of growth are not indicated in X-ray plates.

However, when combined as in this study, with vital staining methods carried out by Schour and Massler, the two most effective methods are collated to give the most accurate picture of bone growth.
1. The mandible is suspended by muscular function with no contact between the alveolar processes at first but as the alveolar processes develop and the deciduous dentition erupts they gradually enclose the tongue.

1. Illustration indicating relation of gum pads in the newborn. (After Brash).
2. Tracing of lateral cephalometric X-ray of three month old infant showing tongue between gum pads.

Brodie makes this inference from the fact that the angle formed by the cranial base and the lower mandibular border remains constant and also the distance between the nasion and the gnathion shows a typical growth curve when graphed.

Superimposed tracings of the same subject at three months and at seven years. Note series of lines indicating stability of relationship of lower mandibular border to cranial base.
Method of superimposing mandibular tracings for the study of changes in the gonial angle. Stages shown are three months, 2½ years, and seven years.

Superimposed series of tracings of mandibles of six different individuals of different age ranges.
By superposing tracings of the mandible at different ages Brodie affirms the fact that the gonial angle does not change although if the condylar angle were taken he recognises that a smaller angular reading would be obtained as age advanced.

In cases of normal mandibles the attainment of the adult gonial angle took place in 3 months in one case and in 18 months in another case. From then on this angle does not change in form or degree.

RATE OF GROWTH

Rate of growth from gnathion to gonion increases steadily with only a slight lessening in intensity until dentition is completed.

Rate of growth of antero-posterior measurement of ramus shows a smaller rate of growth than either the base of the mandible or the length of the upper border of the mandible although the rate is still steady.

Qualitatively there are two processes responsible for this growth, the general and even deposition of bone along the posterior border of the ramus and the resorption of bone at the anterior border of the ramus.

MANDIBULAR HEIGHT

The body of the mandible increases in height at a steady rate both in the incisor region and posterior to the last molar. As the occlusal plane moves steadily downward until maturity and the body of the mandible increases in height one of two processes must take place.

1. The mandible must increase in height by deposition at all its lower borders and resorption at its alveolar borders to permit the plane to descend – or

2. The condyle must grow upward fast enough to permit both increased height of the mandible and the descent of the occlusal plane to take place.

That the second of these alterations is the case can be proved by vital staining techniques.
EXPERIMENTAL FINDINGS

A group of Macaque monkeys were injected with Alizarin Red "S" by Schour and his collaborators.
The animals were also anaesthetised and cephalometric X-rays taken at periodical intervals.
By this double attack
1. Alizarination revealed that up to the age of eruption of last permanent molars growth was very generalised and all the surfaces of the mandible were stained.
2. From the stage of the mixed dentition onwards growth was restricted to definite sites.
3. The most prominent sites were:—
   (a) The posterior border of the ramus
   (b) The head of the condyle
   (c) Sigmoid notch and the alveolar border

All the evidence points to the fact that the growth of the mandible is in a downward and forward direction.

1. Three superimposed tracings of the same individual from three months to eight years. Note the gonion goes downward and backward, while the nathion goes downward and forward.
2. Two superimposed tracings of the same individual at three years and at ten years seven months. (Note continuation of the same trend as in previous figure.)

The forward vector is supplied by a bone deposition at the back of the ramus while the downward vector occurs as a result of the upward growth of the alveolar border against an occlusal plane that is descending. Since there is no tilting of the occlusal plane and no
change in the gonion angle it follows that condylar growth must accommodate the sum of maxillary and mandibular growth.

Moore used a monkey of age comparable to that of a 5 year old child in his experiment in vital-staining with alizarin-Red S. He came to conclusions regarding growth centres which differed from those of Brash in that Moore found the main growth centres were in the sutures of the skull. Other sites of growth some of which are sutural and some surface act as adjustors in order to maintain contact of bones which would otherwise be separated or by preventing disproportionate enlargement of such cavities as the brain case, orbit and nose. Although Moore’s deductions from vital-staining experiments are different to Brash, in some respects this is due to the dissimilar skull architecture of the long snouted pig and the monkey.

Brodie’s study follows on his previous study on growth from 3 months to eight years.

Nineteen subjects in this work were studied in their growth between 9 and 17 years of age.

In this preliminary release of findings Brodie makes the following points.

1. Although the floor of the nose remains fairly stable in some cases the anterior end may drop more than the posterior end.

2. The junction between the pterygoid process and the tuberosity of the maxilla is the most stable area in an antero-posterior direction.

3. The occlusal plane and mandibular border were stable throughout growth in half of the cases and if they do change they tend to become closer to being parallel to the anterior cranial base.

4. The angle N-S-Gn is again shown to remain stable in all except a few cases in which there was a slight increase in the angle indicating a backward swing of the face.
5. However the angle S-N-Gn showed no tendency for a backward movement of the chin.

6. Late changes in growth are accompanied by a combination of the forward and downward movement of the anterior nasal spine and with a falling behind of the dental arch and its supporting bone. This produces a decreased prominence of the denture.

7. The angle B-S-N varies but seems to have little correlation with any changes in the facial mask.

8. The point porion shows a large range of variations in growth behaviour but seems to be independent of any changes in B-S-N angle or behaviour of chin point.

DEVELOPMENTAL ANATOMY AND PHYSIOLOGY OF THE FACE AND JAWS.

From the philogenetic point of view the cranium is enlarging at the expense of the face size.

Weidenreich says that the reduction and transformation of the dentition is a part of a correlative reaction in the process of alteration affecting the entire skull.

In this reduction process however, the teeth and jaws are not always in consonance.

The crowns of the teeth in their tooth germs are of ectodermal origin and are laid down in their final dimensions, while the jaws are of mesodermal origin and show prenatal growth in the intra-uterine period, post-natal growth before the teeth erupt and then growth until about the age of twenty five years.

Since the latter two periods of growth are subject to many functional and environmental and other influences they frequently do not reach a sufficient size to accommodate the teeth in an arrangement which is within the borders of normality.
MUSCLES

Muscle growth is similar in its rate of growth to the body, rapid in infancy and childhood, slower and regular in middle of childhood with an increase in rapidity preceding and during adolescence.

Experimental removal of muscles can affect the bony growth in the region in which the muscle is normally inserted, particularly appositional growth. Where loss of muscle caused decreased growth sutures were simpler than normal.

The facial muscles include:—
A. The muscles of the orbits and eyelids and
B. The muscles of the lips and cheeks.

The muscles of the lips and cheeks are the following:—

1. Orbicularis oris
2. Buccinator
3. Quadratus labii superioris
4. Quadratus labii inferioris
5. Incisivus labii
6. Zygomaticus
7. Caninus
8. Risorius
9. Triangularis
10. Mentalis

Muscles of Mastication

1. Masseter
2. Temporalis
3. External pterygoid
4. Internal pterygoid

The tongue

Certain of these muscles exert a constant tension on the teeth and alveolar bone especially the buccinator some of the fibres of which are inserted into the basal bone of the jaws.

arises

The buccinator posterior to the dentition from the pterygo-mandibular raphe and from the maxilla and mandible in the molar region.
From here it runs across to join its fellow from the other side. The central fibres decussate at the corners of the mouth.

This powerful muscle is modified in its affect on the dentition by the interaction of other muscles which are inserted into its fibres.

The buccinator restrains the tendency for the anteriors to be driven labially by the tongue and other forces and would normally form the arch into a semi-circle were it not for the modifying influence of such muscles as the caninus, triangularis, risorius, orbicularis oris and quadratus labii, superioris and inferioris.

All decussations occur at the corner of the lips and this forms the most active part of the lips.

Thus we have the forces of mastication and deglutition exerted by the various muscles serving these functions tending to drive the teeth forward while we have a muscle band running completely around the denture resisting the spreading tendency on the upper arch. The lower arch is confined by the upper teeth and the forces of mastication tend to drive these teeth lingually but the integrity of the contact points of these teeth arranged in an arch with a little help from the tongue musculature preserve the arch form.

THE FOURTH DIMENSION IN ORTHODONTIA

Brodie in this article analyses the size, rate of growth and development of the teeth, jaws and particularly of the muscles.

He emphasises the enormous number of variations which result from the integration of certain variables.

Teeth once erupted are held in an environment that is completely dominated by the environment. This is the reason why so many malocclusions particularly of the crowded type do not improve once the teeth have erupted and bone is growing.
Muscle when laid down is endowed from the first with the same number of fibres that it will have when fully grown. The difference between the infant and the adult muscle lies in the length and breadth of the individual fibres. The growth of muscle is subject to the same laws of variation in total size attainment, rate of growth and to a lesser extent in form. Muscle however possesses one peculiar characteristic in that it must contract until it reaches a sufficient degree of resistance to stop its shortening.

In the case of the dentition, if jaws growth has not attained the appropriate size for the accommodation of the teeth that have erupted, the muscle being attached to the same bones conforms to the smaller size of the arch and tends to maintain the same degree of tension throughout its subsequent growth. Thus we have a condition in which a temporary disharmony between tooth eruption and jaw growth is perpetuated by the musculature and the malocclusion tends to be maintained by it.

The two opposing muscle masses with which we deal are the tongue on the inside and the buccinator muscles mainly on the outside. These two muscles masses are vastly different in the time of their growth. The tongue is comparatively large at birth and ready for full function in sucking and deglutition. It controls the alignment of the temporary dentition and the usual lack of crowding in this dentition can be attributed to its more or less unopposed influence.

The lip and cheek musculature develops more slowly and attains its full development only in adulthood. Muscle control thus changes from the lingual to the labial in growth.

Brodie gives an interesting description of the development of the jaws and musculature and their effect on the teeth from birth.

At birth the jaws are devoid of alveolar process and the tongue being well grown occupies the entire mouth cavity
and has contact with the cheeks and the lips.

Between birth and 3 months the alveolar process begins to develop and the tongue and the cheeks become progressively more separate as the alveolar process grows, the teeth erupt and come into occlusion.

Tracing of a lateral cephalometric X-ray of a newborn, showing location of first permanent crypts, the lack of alveolar process and the tongue occupying the entire oral cavity.

The interaction of these two muscle masses is now going to determine the alignment, size, and form of the arches as well as the axial positioning of the teeth.

At birth the jaws are large enough to accommodate all 20 deciduous teeth even if these were to erupt simultaneously, hence the absence of malocclusion or better the lack of crowding in the deciduous dentition.

However Brodie states that a potential malocclusion may be present in the form of a malrelation of the jaws or other factors such as a disproportion in the relative degree of development of the tongue on the one hand and the maxilla and mandible on the other.
Lack of integration between tongue size and jaw growth is shown in these tracings at three, six, and eight years; by fourteen and one half years jaw growth had been sufficient to enclose the tongue and thus reduce the malocclusion.

These muscle forces have a great effect on the alveolar process and tooth position while the process is being formed.

In Class II and Class III relationships there is an alteration of muscle forces. In Class II cases the marked deviation from normal mesio-distal relationship of the jaws affects the action of the musculature especially as the buccinator is attached about that imaginary line between the apical base and the alveolar process.

Variations between individuals in the position in which they carry their tongue further complicates the arrangement of the teeth.

In the process of eruption and its effect on the alveolar process it has been shown that a year before the eruption of the permanent central incisors and before the deciduous teeth are lost the crest of the alveolar process is attacked and may be cut off in the form of a sequestra.

This loss can amount to as much as 7 mm. Thus when the permanent teeth erupt the crest of the process must be rebuilt to its old level and beyond this if additional height is required.
Loss of alveolar crest and formation of sequestra prior to shedding of deciduous incisors. Subsequently building of the crest does not necessarily restore the original alveolar height after eruption of the permanent incisors.

This rebuilding of the old level alone requires a period of 3 to 4 years.
The increased height may be as small as 1 - 2 mm. or as great as 10 or 11 mm. and the greatest growth is usually found in the incisor region.
When growth is much greater in the incisal region than in the molar region we have the elements of deep overbite and a large freeway space.
Brodie suggests that bite plate treatment at this stage will result in some further eruption of the molar teeth. The period of transition from deciduous anteriors to permanent ones is critical in more ways than one.
The permanent teeth have to erupt into an arc which previously contained the smaller deciduous teeth and was bounded on the outside by the band of muscle. Unless growth of the jaws takes place and the areas providing attachment for the muscle particularly, a muscle pattern is apt to result that is too small for the age of the child and the eruption of the larger teeth.
Brodie is quite definite that if an the eruption of the first permanent molars a Class II malocclusion becomes evident, then this seems to be the logical time to treat it.
He advises the Oppenheim method of holding back the upper first permanent molars with head cap treatment until the mandible grows forward into a Class I relationship. As this is the period of most rapid mandibular growth, this would seem to be the logical time for best treatment results.

Brodie says that the answer to the question of when to treat a malocclusion is the same as for any other abnormal condition, namely, when it is seen.

Objective of early interference is:-

1. Removal of factors which are slowing growth
2. Prevention of the seemingly inevitable result of a lack of harmony between the eruption of the teeth and the growth of the jaws.
3. In Class II1 cases the adjustment of growth of parts which are out of harmony in their relation to each other.

Early treatment according to Brodie make easy cases out of difficult cases. Cases managed as early as possible show far superior reaction in being less liable to root resorption and showing less effect on the periodontal membrane.

The adaptability of the Temporal and Masseter muscles were studied by Jarabak in various functional situations in a subject with normal occlusion and these were compared to patterns from another subject who had had a cleft palate and hair lip reduced in early childhood and whose teeth went through an excessive occlusal space (17 mm) in going from rest to occlusion. The myograms of the latter patient were also compared when she had an interocclusal splint inserted to reduce the excessive interocclusal space.

**NEURO-ANATOMICAL STRUCTURES.**

(a) A motor unit is made up of a varying number of muscle fibres depending on function and is enervated by branches of a single axon and also has a sensory nerve supply. Motor
nerves can either originate in the brain or at the reflex level from the spinal cord. A motor unit will respond "all or none" when it receives the stimulus. The motor unit of the masticatory muscle has four types of nerve supply.

**MOTOR**
- Nerve impulses from brain
- Reflex impulses from spinal cord.

**SENSORY**
- Proprioceptive carry stimuli from muscle to central nervous system.
- Sensory connection to the periodontal membranes and gingiva.

(b) Muscles vary in colour

1. In dark red muscle, motor units are thought to be structurally designed for slow movements.
2. Pale red muscle is made up of highly specialised motor units capable of rapid action.

(c) Arrangement of motor units in :-

1. Series - muscles designed for greatest shortening.
2. Parallel - muscles designed to carry greatest load.
3. Diagonally - both work and shortening.
Arrangement of muscle fibres according to the work they perform.

Thus in this study Masseter is equipped for power and the temporal for both action and power.

**TYPES OF MUSCLE CONTRACTION**

Three types of muscle contraction have been noted by Hober (1945).

1. That accompanied by shortening of muscle
2. That accompanied by lengthening
3. Isometric contraction in which there is no change in length.

All three types occur in the muscles concerned with chewing. In addition to the physical changes that take place there are also chemical changes taking place in contracting muscles and resulting in the liberation of heat and electrical energy. It is the recording of this electrical energy known as action currents that makes electromyography possible.

A typical myogram has three attributes.

1. Time is in fraction of a second and represents the duration which the fibres of the temporal muscle are contracting for one chewing stroke.
Time during which muscles may contract is dependent on the work they have to do.

2. Amplitude indicates either
   (a) Number of motor units contracting at one time or
   (b) Frequency of contraction of individual units.

3. Form of the myogram indicates variations in amplitude.

An electromyogram representing one chewing stroke, showing amplitude, form and time.

In rest area, mandible is at rest.

(a) Shows first burst with elevation of mandible to occlusal contact.

(b) Shows maximum chewing force exerted on bolus with teeth in occlusion.

Myograms differ on each side according to which is the chewing side and which the balancing side. Also the recordings from the Masseter muscle are much different to those of the temporal muscle.
1. Myograms representing two chewing strokes taken from the beginning of a continuous chewing record from a patient with normal occlusion. (above left)
2. These myograms represent three chewing strokes taken from the record of patients with malocclusion and a large interocclusal space. (above right).
3. Myograms representing the chewing strokes of a subject whose excessive interocclusal space was reduced with an orthodontic splint. (below).

M Masseter amplitudes are not so great but extend over longer time. The peak amplitudes of these two muscles are not synchronous in the masticating cycle.

From the evidence presented by the myograms we may theorise

1. When the subject is chewing on the right side the right temporal muscle elevates the mandible while the right masseter muscle gives power to the stroke.

2. As there is some lower amplitude activity of the masseter muscle between chewing strokes we may infer that this muscle is instrumental in maintaining the postural equilibrium of the mandible.

EFFECT OF EXCESSIVE INTER-OCCUSAL SPACE

Muscular activity was shown as a "confused" pattern in this case. Due to the silence of the masseter muscles to the temporal muscles fall the task of not only elevating the mandible but also giving the necessary power to the masticating stroke.
EFFECTS OF ORTHODONTIC REHABILITATION ON THIS PATIENT

Inter-occlusal space was reduced to 3 mm.
The contraction phase of the temporal muscles was divided into three bursts with the last showing the greatest amplitude.

This would be due to the fact that with the denture placed the patient has to feel around with his teeth before he actually brings the fibres of the temporal muscle into full contraction.
The masseter muscle silent before rehabilitation once more showed distinct activity.

These experiments show the adaptability of these muscles both in response to stimuli from the voluntary nervous system and from the proprioceptive sensory stimuli originating in the teeth and periodontal tissues.
The findings of this investigation indicate quite clearly that the static concept of occlusion will have to be discarded and replaced with greater realisation of the dynamic machine composed of bone, muscles and teeth with which we are dealing.

This is an excellent article by Jarabak. Experiments have been carried out most thoroughly and employing as few variants as possible he has been able to make some important deductions from his findings.

A difficult subject has been most painstakingly and clearly explained in this article. From the amount of valuable data which has been gathered these small experiments it can easily be seen that electromyographical studies in the future are going to furnish a wealth of information not only useful to the orthodontist but also to other branches of dental science.
Moyers studied the action and function of the muscles of mastication by electromyographic analysis.

The muscles studied were:
1. Temporal muscle
2. Masseter muscle
3. Internal pterygoid muscle
4. External pterygoid muscle
5. Suprahyoid muscles.

Subjects were chosen who had a normal dento-facial growth pattern, normal occlusion of the teeth and a freedom from any temporo-mandibular articulatory difficulties.

RESULTS

Electromyographic records serve as a key to the nature of muscle contraction. Amplitude of the spikes are in proportion to the strength of the contraction.

MOVEMENTS OF THE MANDIBLE

1. Opening or mandibular depression

The first high amplitude action potentials are seen in the external pterygoid which is closely followed by the digastric. They both soon reach a normal height and persist until opening is completed.

2. Elevation of the mandible

The internal pterygoid, masseter and temporal muscles all display high amplitude spiking during elevation.

3. Lateral mandibular movements.

Primary movement of this type is brought about by contraction of the external and internal pterygoid muscles acting unilaterally. Secondary contractions are seen in the suprahyoid and the masseter muscles.

4. Protraction

The internal and external pterygoid muscles seem to be exclusively responsible for this action.

5. Retraction

Middle and posterior fibres of the temporal muscle are primarily involved and the other fibres of the temporal muscle to a lesser extent. Active contractions are seen in
the anterior belly of the digastric muscle.

**ELECTROMYOGRAPHIC ANALYSIS OF INDIVIDUAL MUSCLES.**

1. Temporal muscle
The fibres of this muscle can be divided into three separate parts and each acting in a different direction. It is the prime mover in the elevation of the mandible.

2. Masseter muscle
The primary function of the masseter is to aid in elevation of the mandible and it assumes a more dominant role if the mandible is being protruded during elevation.

3. Internal Pterygoid muscle
This muscle is the third of the elevators of the mandible and contracts strongly during simple protrusion. Unilateral contractions of this muscle result in contralateral abduction of the chin point and in this movement it is joined by the external Pterygoid of the same side, and the temporal muscle of the opposite side.

   Its most common task is the lateral shifting of the jaws and the rotary movements associated with chewing.

4. External Pterygoid muscle
This muscle's principal task is that of drawing forward the meniscus and the condyle head. In mandibular depression this muscle is the prime mover. The muscle is involved in a secondary fashion in many other movements of the mandible.

5. Supra hyoid muscles.
This digastric demonstrates spiking in all mandibular movements but rather in a secondary role to other muscles. It stabilises these actions but does not initiate them.

This research of Moyers is an important step in the better understanding of muscular influences.

While these muscles may be dissected out one by one and their anatomical origins and insertions investigated and deductions made from these of the possible mode of action of the muscles, the electromyographic analysis furnishes us with the following data which cannot be gathered in any other fashion.
1. The muscles involved in the various mandibular movements
2. The muscles responsible for the instigation of these movements
3. The muscles involved secondarily in these movements
4. Relative degree of Synergistic movement of each muscle involved.
5. An indication is given of the type of muscular contraction by the amplitude of the spikes.
6. The order in which each muscle becomes involved in a movement involving several muscles.
7. The ability to differentiate to a certain extent between the actions of the three groups of fibres of the temporal muscle.

As has been the case apparently in other muscular systems of the body, continued research using these methods must unearth facts which will be of great value in our understanding of the role of the muscles both in good occlusions and in malocclusions.

THE TEMPORO-MANDIBULAR ARTICULATION

This joint is composed of a sliding hinge mechanism in which the condyle of the mandible articulates with the glenoid fossa of the temporal bone. It is bounded anteriorly by the articular eminence and posteriorly by the post-glenoid tubercle of the temporal bone. The articular eminence allows the condyle to move downward and forward and thus changes the centre of rotation of the mandible. The articular capsule of the fibrous tissue encloses the two elements of the joint and they are separated by the articular disc.

The presence of this disc allows extensive movements of the mandible, downward and forward and laterally in the function of mastication.

The relation of the condyle to the glenoid fossa is of importance in the evaluation of treatment results especially as various operators have claimed to have changed the
relationship in the process of treatment particularly of Class II cases with very beneficial results as far as the occlusal relations of the teeth are concerned.

FORM AND FUNCTION OF THE JAWS

In addition to the genetic pattern the morphology of bone after birth is modified by function and the necessity to bear stresses generated by muscular and other forces. During mastication each time the muscle contracts the mandibular teeth are brought into contact with the maxillary teeth and these pressure forces are transmitted to the maxilla.

The mandible which is delivering the blows against the maxilla has to be sufficiently strong itself. For this purpose it possesses a thick cortical layer of compact bone which is further strengthened along the lower border of the mandible.

In the maxilla the stresses are divided up into forces on the three pillars of the maxilla and are in turn dissipated in the bones of the skull.

The forces of muscular stress produced in the jaws are essential for the proper development of the jaws, particularly in the jaws of the growing child.

TRAJECTORIES OF THE JAWS AND STRESS LINES IN SOFT TISSUES

Benninghoff studied the natural line of stress in bones by piercing small holes in the bones of fresh skulls with an awl. When the skulls were dried these holes took on linear form. These lines formed the "Benninghoff's lines" or trajectories and indicate the direction of functional stress on bone. They follow the pattern of the bony trabeculae in the spongiosa within the bodies of the jaws. These lines are most easily demonstrated in the following diagrams.
Profile of a skull showing Benninghoff’s lines of stress or trajectories.

Fig. 91. Benninghoff's trajectories in the edentulous mandible.

1. Benninghoff's trajectories in the edentulous mandible.
2. An oblique view of the base of the skull, showing Benninghoff's trajectories, or lines of stress, passing through the maxilla and being distributed at the cranial bones.

The basal arches of the maxilla and mandible and the distribution of the bittresses of the maxilla. The basal arches are the shaded portions of the jaws.
The maxilla like other bones follows Wolff's Law and provides a maximum of strength with a minimum of material. This is accomplished by the formation of three bony buttresses and a bulk is kept at a minimum by the formation of the sinuses.

The Benninghoff lines follow these buttresses in the maxilla and it is through them that the stresses of mastication are dissipated in the bones of the skull. They are:

- Fronto-nasal buttress, the Molar-zygonatic buttress, and the pterygoid buttress.

In a study of the natural lines of tension in the skin, Langer made holes in the skin of cadavers and noted the direction these holes took when the skin was stretched. These lines of stress influence facial appearance and must be taken into account when attempts are made to improve facial appearance by orthodontic therapy or facial surgery. The muscles, skin, and other soft tissues play as important a part as the morphology of the bony skeleton in the shape and appearance of the face.

**GROWTH BEHAVIOUR OF THE HUMAN BONY FACIAL PROFILE AS REVEALED BY SERIAL CEHALOMETRIC ROENTGENOLOGY.**

Lande's work on growth behaviour of the facial profile was based on serial cephalometric X-rays and lateral head plates were traced according to Broadbent's technique. The points used in his study are shown in the following tracings.
Lande used three groups for comparison namely: three to seven years, seven to twelve years, twelve to eighteen years. In a study of 34 males he found that the mandible tended to become more prognathic in relation to the brain case during growth but the maxilla showed little change. This increase in mandibular prognathism generally occurred after seven years of age.

The lower border of the mandible became more horizontal with the increase in prognathism.

The convexity of face decreased with age.

Alveolar bone growth did not keep pace with the growth of its skeletal base.
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HELLMAN'S DEVELOPMENT STAGES.

Hellman divided facial growth into seven developmental stages based on relation between patterns of dentition attained at certain stages and bearing a relation to the growth of the face and the development of the dentition.

Stage 1. Early infancy before the completion of the deciduous dentition.

II. Late infancy when deciduous dentition is complete.

III. Permanent first molars in position and some or all of deciduous incisors have been replaced.

IV. Second permanent molars erupting or in position and some or all of the deciduous canines and molars are being replaced.

V. Adulthood when third molars are erupting or have taken their place.

VI. Period of old age where occlusal surfaces of molars are worn off to the extent of obliterating their grooves.

VII. Period of senility when at least half of the crowns have been worn off and most if not all of the teeth have been lost.

As the stages of II to V are of main interest in orthodontia, Hellman subdivided these stages.

II A. Completion of deciduous dentition

II C. Beginning of eruption of first permanent molars

III A. Completion of eruption of all first permanent molars and some or all permanent incisors.

III B. Shedding of deciduous canines and molars and eruption of their successors.

III C. Beginning of eruption of permanent second molars

IV A. Completion of eruption of permanent second molars.

IV C. Beginning of eruption of third molars

V A. Completion of eruption of third molars.
Hellman found that facial growth in girls to be considerably in advance of that in boys.
Hellman concludes from his study of developmental stages.
"If orthodontic treatment of cases of malocclusion were initiated during the period of maximum facial growth, results should be obtainable in shorter time, with less effort to the orthodontist, more comfort to the patient and greater satisfaction to all."

Prevention of malocclusion may be practised even before the teeth have erupted by careful observation of the antero-posterior relation of the gum pads. The child is barely able to approximate the gum pads in early life hence its desire to chew fingers in order to bring pressure to bear as an aid in the eruption of teeth. These fingers should be replaced with a hard rubber object so that the sucking habit does not become implanted.
Dental care is essential in the deciduous dentition to obviate the premature loss of these teeth.
Sillman (1) maintains that in the child with the potentiality of developing a good occlusion the early loss of deciduous teeth causes little change in the anteroposterior relationship of the dental arches. However in cases with poor occlusion potentialities, changes are noted.
Teething difficulties arise when teeth erupt posterior to the true gum pad regions in which positions the connective tissue is much tougher.
In the deciduous dentition spot grinding will relieve some occlusal defects.
Sillman goes one stage further in his studies of occlusion in this article and particularly in the early predental stages he seems to have a monopoly of research and presents some interesting facts on early recognition of potentialities of occlusions and their treatment.
Prenatal Development of Dentition

The dental lamina is formed about the sixth week of intra-uterine life and formation is continued into the phase of calcification which begins at the 4th month and extends to the sixth month of intra-uterine life.

Proliferative growth and differentiation of the permanent dentition begins before birth excepting that of the premolars, lateral incisors and third molars.

Diagrammatic representation of the life cycle of a tooth.

Post-Natal Development

At birth although the alveolar process is very little formed a lateral X-ray reveals the 20 deciduous teeth in various stages of formation and also the crypt of the first permanent molar.

Contrary to the opinion of Braasch, Brodie and Sillman affirm that at birth the gum pads are not in apposition but are wide apart and portions of the tongue fill the gap between the pads and support the lips and cheeks.

As the teeth erupt and jaws develop the tongue is gradually encaged in the ring of erupting teeth.

Sillman has traced the development of 48 cases from birth to 7 or 10 years of age. Half of these cases he has followed to 7 years and half to the age of 10.
He has classified the gum pads into four classes. At birth the gum pads are segmented to correspond to the deciduous teeth and between the canine and first deciduous molar there is the well defined lateral sulcus which persists into the later life of the child.

By measuring the antero-posterior differences between the lateral sulci in the maxilla and mandible Sillman arrives at a measurement varying between 0 and 8 mm. in 161 children at birth with a mean of 2.6 mm.

CLASSIFICATION OF GUM PADS.

Class A. Maxillary and mandibular anterior segments in their respective planes.

B. Incisal segments higher than canine segments in maxilla, in mandible anterior segments in same plane.

C. Incisal segments higher than canine segments in maxilla, in mandible canine segments higher than in incisal.

D. Maxilla segments in same plane, in mandible canine segments higher than incisal.

From his analysis of the 48 children studied, Sillman suggests that Classes B.C. and D. at birth are more likely to develop a poor occlusion.

Another finding he made is that of 4 children with an asymmetrical opening all developed malocclusion. He divided the 161 cases in which he measured antero-posterior distance between lateral sulci into two groups, 0-3 mm. - about equal good and bad occlusions developed, 4-8 mm. - mostly bad occlusions developed. Sillman says that poor occlusion may be foreshadowed at birth by the width of the gum pads. Sillman (2) studied the development of the occlusion in 4 children from birth to 12 years of age.

The general health of these children was good and one child had a good dental history while the other three suffered various dental misfortunes for example premature loss of deciduous molars. Despite these, all four children devel-
oped good occlusions at 12 years of age.
Points of measurements and reference made by Sillman for
this study and his previous study are illustrated in the
representations below.

Occlusal view of cast at birth and twelve years of age
illustrating points of measurements.

Illustrates some anatomical landmarks at birth C.P. Canine
Papilla; D.G. Dental Groove; G.G. Gingival Groove; E.E.
Everted Edge; L.S. Lateral Sulcus; P.L.S. Posteralateral
Sulcus; N. Median notch.
Sillman has collected masses of data and from his statistical methods which seem to be most thorough has come to the conclusion that the good fortune which these children enjoyed in possessing a good occlusion at the age of 12 years can be attributed in the main to good development of the jaws which was maintained despite various dental misfortunes.

The development of dental height according to Diamond (3) is concerned with the problem of growth and the rate of growth. This rate is never regular and each part and organ has its own rate of growth and its own cycles of acceleration and retardation.

While growth cycles of acceleration and retardation are independent for each part of the body there must be some interrelation between the growth cycles of adjacent parts. Diamond states that growth of the jaws and development of the jaws in no way influences or interferes with the growth and development of the teeth or vice versa. Therefore if the mandible or maxilla are retarded the teeth will still grow normally and erupt but will lack the necessary space.

The general overall rate of growth of the body steadily diminishes from gestation to maturity.

The body increases in length 30% in first 6 months but increases only 50% in first year of life.

The diminishing general rate of growth also applies to the development of the teeth.

Growth of first permanent molar which is the largest crown begins development at birth and is completed in 2½ to 3 years.

Growth of maxillary permanent central which is much smaller begins only 3 to 4 months later and takes to 4 to 5 years for its completion. Diamond gives his definition of DENTAL HEIGHT as those parts of the jawbones within which
teeth are developing, plus the teeth in their later varying states of clinical eruption. This is contrary to the usual definition of dental height which is the area occupied by erupted portions of teeth. Diamond quotes Milo Hellman.

"With the appearance of the dentition there is a sort of wedging apart of the maxilla from the mandible. The increase in the dimension of height is thus brought about not only by the vertical growth of the face but also by the addition of the combined height of the crowns of the teeth separating the two jaws."

Diamond studied twelve cases of delayed eruption of six year molars. His views deduced from these cases seem to be opposed to the theory of Hellman in regard to the eruptive forces of the teeth wedging the jaws apart. In the twelve cases studied by Diamond there was adequate mesio-distal space for accommodation of teeth but teeth did not erupt but continued to form until root formation was almost complete. Lack of intermaxillary space was evidenced by the fact that the edentulous posterior gum pads were in contact and the anterior teeth were in overbite relation. The lack of intermaxillary spaces was due to retardation of growth of ramus and was responsible for the submerged teeth. Diamond deduces from his evidence.

"The force of eruption, therefore, plays no part in increasing the intermaxillary space by wedging the jaws apart and plays no part in increasing the vertical dimensions of the dental height." Instead Diamond says. "Growth in length of the ramus is responsible for increase in vertical height, thus permitting vertical growth of the maxilla and of the body of the mandible as well as the clinical eruption of the teeth."
This study by Wylie (4) aims to establish what relationship if any, exists between ramus height, dental height, and overbite. The data was derived from cephalometric tracings of 61 females and 29 males.

The above measurements were used in the analysis of this area. According to Wylie 73% of orthodontic cases have either medium or severe overbites. He says that the development of intermaxillary space is not dependent on development of ramus height and that there is no evidence to support the theory of "growth spurts" in the observation of accurately oriented cephalometric films of craniofacial growth but he admits that the "springing up and filling out" periods to occur in other parts of the body. This article by Wylie is an attempt to refute all of Diamond's theories.

Wylie quotes Brash as having shown the importance of alveolar bone growth in increasing the vertical dimensions of the face. In his eagerness to attack Diamond, Wylie has apparently forgotten to read Brash's works and to relaise that Brash was unaware of the major part the condylar growth centre plays in the growth of the man-
ible and knew only of the alveolar growth from his experiments in pigs.
He quotes the work of Brodie and Thompson on the importance of considering the relation of the jaws in dynamic rather than centric occlusion. The factor of freeway space is possible variable in the determination of the relationship of between ramus height, and overbite but dental height can only be calculated with the teeth in centric occlusion.
Wylie concludes that total face height, lower face height and intermaxillary space in the molar region are less in closed bite cases but there is no significant difference in ramus height. He goes further to say that Diamond's contention that decreased intermaxillary space and consequent closed bite are due to lack of ramus growth is not substantiated by this study.
While adequate ramus growth is essential to facial harmony it has no direct relationship with the degree of development of intermaxillary space.
These two articles by Diamond and Wylie are practically diametrically opposed in their deductions. It is refreshing to find two men, particularly two so well versed in the science of orthodontics as Diamond and Wylie expressing definite opinions on a controversial subject. Diamond in my opinion is quite right in his statement that the intermaxillary space is determined by the growth of the ramus in length.
In the early years of life some downward growth of the temporal bone and some growth of the ramus are the factors involved in the lowering of the body of the mandible in relation to the cranium. Intermaxillary space is thus provided for the eruption of the deciduous teeth. Thereafter intermaxillary space for the subsequent eruption of the permanent teeth is determined by growth of ramus length. This article by Wylie is not up to his usual standard and in this case I think his judgement has been
warped by his eagerness to criticize Diamond.

The clinical studies by Cohen (5) add further light on this problem of development of dental height. Cohen has traced growth and development of the teeth and jaws clinically and radiographically on six children.

(a) Two of these children had ectodermal dysplasia, one with complete anodontia, the other with partial anodontia.

(b) Two young pituitary dwarfs.

(c) Two children who had teeth absent in their jaws.

1. Maxillary and mandibular casts of case with ectodermal dysplasia at the ages of five and eight.
2. Casts of case with ectodermal dysplasia at the age of five years, compared with casts of two normal children at the age of five.
3. Casts of case with ectodermal dysplasia at the age of eight compared with casts of two normal children at the age of eight.

The above illustrations show that the jaws of the child with complete anodontia compare favourably with two normal children of the same age. Dentures have been worn for two years successfully, temporo-mandibular articulation appeared normal, suggesting that growth in ramus length is not interfered with in ectodermal dysplasia with complete anodontia of the teeth and that the jaws develop
independently of the teeth.
In the second case of ectodermal dysplasia with partial anodontia lateral views of the casts showed that the intermaxillary space had developed. Since it was physically impossible for anterior teeth to wedge the jaws apart because of missing maxillary incisors this space had developed by the downward growth of the temporal bone together with an increase in ramus length which created sufficient space for the deciduous molars to erupt. Continued observations of this child revealed normal jaw development antero-posteriorly and laterally with the downward growth of the temporal bone and ramus length growth providing the intermaxillary space for erupting teeth. Normal bone development was present with no alveolus in the edentulous areas.
(b) In the child suffering with pituitary dwarfism there was a failure of the intermaxillary height to develop which could be attributed to an arrest in ramus length growth because of the generalised osseous retardation of skeletal development, a manifestation of pituitary dwarfism.

The failure of the intermaxillary space to develop in this case led to the inhibition of the vertical growth of the alveolar processes in both jaws and markedly retarding the eruption of the permanent teeth. Failure of dental height to increase in this dwarf can be attributed primarily to an arrest in ramus length growth.
Maxillary and mandibular casts of case with pituitary dwarfism from three years six months to ten years nine months.

The adult case of pituitary dwarfism bore out the assertion that lack of ramus length growth is responsible for deficient intermaxillary space.

(c) In these two cases of normal children, with partial anodontia, it was not possible because of lack of occlusion of incisors in erupting to wedge the jaws apart. Nevertheless sufficient intermaxillary space developed to accommodate the deciduous molars. These cases confirm that in the early life it is the downward growth of the temporal bone and the ramus length growth which create the intermaxillary space for the eruption of the deciduous teeth.

The investigation carried out by Cohen I have treated rather fully as I consider both his researches and the presentation of his paper one of the best I have read. The evidence is set forth clearly and concisely and illustrated well with clinical and radiographic reproductions. His results bear out the findings of Diamond and throw further light on some important facts which bear repeating.
The teeth and the jaws develop independently of each other.

During the early years of life the downward growth of the temporal bone and the ramus length growth create the intermaxillary space for the eruption of the deciduous teeth.

In ectodermal dysplasia the intermaxillary space develops normally since there is no retardation in skeletal development.

Where there is retardation of skeletal growth as in pituitary dwarfism, ramus length growth is impaired and the intermaxillary space fails to develop.

When anodontia occurs in the anterior part of the mouth in normal children it is impossible for the teeth to wedge the jaws apart. This proves that the intermaxillary space which does develop in these cases is not due to the wedging effect of erupting teeth.

The findings in the cases of ectodermal dysplasia with partial anodontia and the child with pituitary dwarfism indicate that there are specific genetic determinants for the teeth, the maxilla and the mandible.

Cohen concludes with the statement that the above observations suggest that the development of the intermaxillary space is predetermined by hereditary factors. In the absence of disease or trauma, normal development can be anticipated.

Broadbent (6) in his article uses the records of the Bolton Fund which at the time contained cephalometric records made during 12 years of 5,000 Cleveland children.

At birth the jaws contain the partially calcified crowns of the twenty deciduous teeth and the crypt of the first permanent molars. Then ensues a period of rapid growth and development pausing at three years with the full
eruption of all the deciduous dentition. Broadbent emphasises the short comings of the measurements of skulls of dead children to give information on eruption of the teeth. In contrast monthly X-rays give a comprehensive record of the progress of development in the same and different individuals. Eruption in its broadest sense begins with the appearance of the crypt in the bone, includes the migration of the crypt through bone and continues after the cutting of the teeth into the mouth. By nine months the increase in size of the teeth is accompanied by the erupting of the incisors into the mouth. At one year when the first deciduous molars are appearing in the oral cavity, the X-rays show the crypts of the permanent incisor and cuspid teeth migrating forward. The rapid rate of growth of the jaws continues until by the third year all the deciduous dentition are in occlusion and fully erupted and the crowns of the first permanent molars are completed.

Developing dento-facial patterns of an individual from one month to the completion of the deciduous dentition at three years.

By superimposing the Bolton base planes of each X-ray in the series it is possible to trace the changes in relative positions of each tooth as it progresses toward maturity.
Broadbent emphasises the shifting and tipping of the permanent dental organs as the face expands. His studies on living children clearly indicate that a tooth at various times may progress in three distinctly different ways.

1. The growing tooth may remain stationary while its forming end grows away from the incisal or occlusal surface into the bone.

2. It may migrate rapidly through the bone with but little increase in length.

3. Increase in tooth length and migration through the bone may occur simultaneously.

The completion of the deciduous dentition occupies three years and it maintains its function through a further three years until the eruption of the first permanent molar ushers in the most complicated period in the development of the dentition, the mixed dentition period in which the shedding of the deciduous teeth and their replacement occupies another six years.

Developing dento-facial patterns from five to nine years.
Lateral and frontal views in Frankfort relation of a child's skull at five years. Dissection exposes location of the twenty eight permanent tooth grounds.

At six years the jaws contain the crowns of twenty eight permanent teeth, densely packed.
it is
Broadbent says that at this stage, that is the replacement of the deciduous dentition by the permanent, when we will see if the individual has had the good fortune to have enjoyed normal developmental health which will be evidenced in the sufficiency of the development of the bony skeleton of the supporting structures of the teeth. If not when the large permanent teeth begin their eruption they will be forced into malocclusion.

To quote Broadbent:

"Since the advent of orthodontic procedures, the common belief has been that expanding the dental arches by mechanical means more or less insured and maintained normal articulation of the teeth in both dentitions. In children with retarded development the skeletal structures are inhibited in their growth in all three planes of space. Therefore it does not follow that expansion of the deciduous or mixed dental arches in only two directions can be expected to alter the supporting structures, (particularly in the vertical dimensions) except the portions which offer immediate support to the teeth themselves."

Over a period of fifteen years during which Broadbent has accumulated serial records of over 1,000 treated cases he is convinced that even though the correction of malocclusion of the teeth may be accompanied by some change in the alveolar process, there is little actual alteration in the bony contours.

Broadbent's serial X-rays taken simultaneously laterally and antero-posteriorly furnish an understanding of the eruption and development to maturity of six upper incisors particularly in the "Ugly Duckling" stage between the ages of 8 to 12 years.
Developing dento-facial patterns from nine years to eleven years.

Frontal dental patterns from X-rays of the same individual showing normal axial changes of erupting incisors and cuspids during the "Ugly duckling" stage of developmental growth in the mixed dentition.
Broadbent advises strongly against interfering with incisor alignment in this age group and his records show that it is essential not to encumber the natural development with mechanical interference.

When the last of the deciduous teeth are shed, the first permanent molars which up to this time have occluded end to end adjust themselves to the normal adult articulation. The cuspids force their way in between the laterals and first premolars and in so doing force the premolars distally to take up the space resulting from the difference in mesio-distal diameter of the deciduous molars and their premolar successors.

If this process of normal articulation takes place despite dwarfed facial bones it creates the impression that the teeth and dental arches are too far forward in relation to the cranial base. This condition is commonly referred to as bimaxillary protrusion.

Broadbent says that it may be clinically bimaxillary protrusion but developmentally it is the result of physical handicaps that have left a permanently dwarfed skeletal structure.

In other words the condition and appearance is due more to the retarded skeleton than to the dentition being too far forward in relation to the cranial base.

As the face develops additional room is required for eruption of the second permanent molars. This is obtained by the forward migration of the anterior two-thirds of the face and partially by backward growth of the posterior third of the face.

As the normal face completes its progress toward maturity room for the third molars becomes available and they enter the oral cavity to complete the permanent dentition.
Continuation of the developing dento-facial patterns of the same individual.

Here once again if development of the skeletal base is inadequate we find the third molars with insufficient space in which to erupt.

This failure in growth is also according to Broadbent exemplified in the anterior section of the arch where the anteriors are crowded for space. Broadbent says that factual evidence collected by the Bolton study over 12 years has failed to support the contention that pressure of impacted third molars caused the buckling of the anteriors but maintains that they are fellow sufferers with the third molars in a general dearth of space.
Bolton Standard of Calcification. Shaded area shows amount of calcification at various ages as recorded in the standardised X-ray.

Brodie (7) in his article divides the face into three areas for the simplification of the study of growth and eruption of some of the teeth.

For a study of the eruption of the deciduous central incisors he uses the palate as a stable plane and the posterior nasal spine as a fixed point. Although the P.N.S. moves directly downward in growth and the A.N.S. forward and downwards this plane remains parallel in each position to the ones preceding.

A line drawn from the Nasal Spine to the tip of the deciduous incisors will form an increasingly large angle with the NS-PNS plane until the tooth goes into function. Then the angle stabilises and the line lengthens thereafter.

The line formed by joining the incisal points maintains a straight direction.

The increase in the angulation in the earlier part of development is due to the eruptive movement added to the normal facial growth movement.

Actually the path is the same and the permanent incisor behaves identically and remains in the line although continuing downward and forward.

The study of the upper molars shows a different result.
The reference line in this case is the S.N. line, or anterior cranial base and a line dropped from the sella-turcica to the point between the mesial and distal buccal cusps of the molars. This angle also increases with age in the case of the second deciduous molar, but since the point of the angle, the sella turcica is stable the effect is different. The tooth drops steadily in a vertical direction in a parallel downward course to the P.N.S. until it comes into occlusion.

The first permanent molar follows a similar line only more posterior until it comes into occlusion but at this time it is found on a line which connects the gnathion to the sella turcica. The second and third permanent molars follow a similar path but more posterior to the first. As well as this general directional movement shown in the X-rays, the X-rays show certain other movements of the tooth itself. When first picked up by the X-ray the occlusal surface faces almost distally but gradually rights itself and even when it breaks the surface it still looks backward and buccally.

**GROWTH PATTERN OF THE MANDIBULAR TEETH**

At the age of three months the crypt of the first permanent molar can be seen in the ramus at a higher level than the unerupted second deciduous molar. Successive X-rays reveal a changing relation. As the second deciduous molar begins its eruptive trend it appears level with the crypt of the first permanent molar which is now in the inner angle of the mandible. Later we find the second deciduous molar higher than the first permanent molar, which by this time is well within the body of the mandible.

The growth of the body of the mandible plus the growth of the alveolar process, plus the eruption growth accounts for the rapid movement of the second deciduous molars.
In relation to the first permanent molar and coupled with the fact that bone is being deposited on the posterior border of the ramus and resorbed on the anterior border gives the effect that the first permanent molar has burrowed its way downward and forward.

Brodie by measurements of the mandible and its molars has proved that each succeeding molar erupts at the same distance from the posterior margin of the mandible measured along the occlusal plane.

**GROWTH OF THE MANDIBULAR MOLARS AND INCISORS IN RELATION TO THE CRANIUM,** would appear to be upward and forward.

If we study only tooth-jaw relation in both mandible and maxilla, eruption is found to be in an almost vertical direction.

**ERUPTION OF TEETH.**

Investigation of eruption have been pursued in the past by four methods:-

1. Clinical
2. Histological
3. Vital staining
4. Cephalometric roentgenography

1. Clinical methods are by far the oldest methods and the times of the teeth appearing through the gum have been correlated with most other factors such as, sex, nationality, nutritional, standards etc.

2. Histological methods have involved investigators in a great deal of work and controversy.

Weinman and Siker describe eruption as a differentiative growth between the teeth and the surrounding bone, and divide it into two phases.

(a) The pre-functional phase

(b) The functional phase.

(a) The prefunctional phase starts with the growth of the tooth and the proliferation in the pulpal tissue generates the slight pressure necessary for the axial movement. This pressure is exerted on the hammock ligament in which the growing end of the tooth rests and which is slung in the
bone of the crypt.

Root growth will not alone account for the distance of eruption of the tooth. Weinman and Sicher attribute this additional movement to growth of bone in the fundus of the crypt. Thus growth of the root plus growth of the bone equal the distance erupted.

The hammock ligament acts as a cushion and prevents the growing bone from encroaching upon the growing root or vice versa.

All other movements of the erupting tooth are accompanied by deposition of bone behind and resorption in front of the moving tooth.

(b) Once the tooth reaches the occlusal plane it enters the functional phase during which we have differential growth between tooth and the surrounding bone. The different growth patterns of cementum and bone results in movement of the tooth.

Growth of cementum at the apical area particularly elongates the tooth to compensate for the loss of tooth structure by attrition.

3. **VITAL STAINING**

Hoffman and Schour measured the rate of eruption of rat molars by means of injections of Alizerin Red S. at definite intervals. They found that the rate was greatest just prior to establishment of occlusion and diminished with age.

4. **ROENTGENOLOGICAL METHOD**

This method was introduced by Broadbent and he has pointed the following facts:

1. The growing tooth may remain stationary while the forming root grows into the bone.

2. The tooth may migrate through bone with little addition to its root length.

3. Root length addition and migration may take place simultaneously.

Carlson (8) studied a series of lateral and antero-posterior X-rays from which tracings were made. There were five series each of a single child with normal occlusion and each
extending over ten years. Overlapping ages were taken so that the whole study was a record of the range from three months to seventeen years.

A line tangent to the lower border of the mandible was used for reference and measurements were made.

1. To the lowest point of the root end
2. To the highest point of the crown
3. To the occlusal plane directly over the tooth.

FINDINGS

1. Teeth showed a constant increase in distance between tip of crown and lower border of mandible
2. During period of crown formation of some teeth, notably the lower canine there was a constant decrease in the distance between open end of crown and lower border of mandible.
3. With beginning of root formation, the distance between root end and mandibular border decreased. As crown tip continued occlusally there must be actual downward growth of root.
4. Following downward growth of root end, there was a rapid increase in eruption.
5. This period of rapid eruption continued until tooth came into occlusion when there was a sudden slowing down.
6. With attainment of occlusion, root then decreased its distance from border until root formation was completed.
7. Once root has completed, the entire tooth again moved up at same rate as occlusal plane.
8. Rate of eruption differs in teeth and between individuals.
9. Greatest rate of eruption lower second premolars, 8 mm. in six months.
   Lower centrals 12 mm. in one year.
   Lower canine 13 mm. in two years.
10. Increase in rate of eruption takes place long before clinical emergence of crown.

11. Clinical emergence does not increase or decrease rate.

12. Rapid eruption does not start until crown is fully formed.

SUMMARY AND CONCLUSIONS
During period of crown formation there is very little eruptive movement and the increase in size of crown generally is expressed in an occlusal direction. Early root formation results in a downward growth of 2-4 mm. Then entire tooth begins most rapid phase of eruption until occlusion is attained when eruption slows and root is completed downward. Then tooth rises with occlusal plane only.

Schaeffer (9) prefaces his growth study with a summary of previous findings in the axial relation of the incisors in good occlusion and in malocclusion and also the stability of the incisors after treatment.

Schaeffer in this study relates the maxillary incisors to the palatal plane and the mandibular incisors to a plane drawn through gonion and gnathion.

The construction of the points and planes is shown in the following figure.

Diagram to indicate points and planes used in this study.
The material used was serial X-ray studies over a period of about eight years. Schaeffer found three trends in the angle of the lower incisors to the Go-Gn plane. In one pattern the axial inclination remained stable and in the other two it either increased or decreased.

One point of interest which Schaeffer notes is that irrespective of the change or otherwise in inclination the incisors assume a more posterior position on the body of the bone than it held originally after a period of growth.
RELATIONSHIP OF THE MAXILLARY INCISOR TO THE PALATAL PLANE
was found to follow three similar patterns to lower incisors and the maxillary incisors was also found to be posterior in position in comparison to its original position after a period of growth.

Angular pattern formed by the maxillary incisor to palatal plane.
Angular patterns formed by maxillary incisor to mandibular incisor.

Relationship of maxillary and mandibular incisors was also found to divide up into three patterns. In one the angle decreased in another it remained stable and the third group it increased.

For superimposed tracings:
- Earliest approximately 8 years
- Latest approximately 18 years
Go - Gn Plane to Palatal Plane

According to the findings the changing of relationship between the upper and lower incisors could not be attributed to changes between these reference planes.

**FINDINGS IN CLASS II MALOCCLUSION**

As only six cases were studied I consider that findings are of no significance.

This is an interesting and informative article and original in the respect that the study is of a serial and longitudinal nature whereas most of the previous methods have been of a cross sectional averaging nature. The findings bear out previous studies on incisal relationship as far as the mean or average are concerned. The wide extent of the ranges outside the mean found agree with previous investigations except those of Tweed.

Schaeffer emphasises and rightly so that in view of these ranges it is folly to employ a mean as a criterion for a single individual and he adds that it would seem impossible to employ limited angular measurements as absolute criteria in either prognosis or treatment planning.


