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DIRECT MEASUREMENT
OF THE
FRANKFORT - MANDIBULAR
PLANE ANGLE.

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A thesis submitted in partial fulfilment of the requirements for the degree of Master of Dental Science at the University of Sydney.

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1982.
DEDICATION

"What do you think, Keith?" ....

I would like to dedicate this thesis to my wife Carolyn for her love and understanding during the many difficult phases of its preparation and to my mother and father for their support and encouragement at all times.

.... "type it again, Carol".
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>List of figures</td>
<td>v</td>
</tr>
<tr>
<td></td>
<td>List of tables</td>
<td>vi</td>
</tr>
<tr>
<td></td>
<td>List of diagrams</td>
<td>vi</td>
</tr>
<tr>
<td></td>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Literature review</td>
<td>4</td>
</tr>
<tr>
<td>Chapter 1</td>
<td>Anthropometry : A Brief History of Cranioometry, Cephalometry and Early Roentgenographic Cephalometry.</td>
<td>5</td>
</tr>
<tr>
<td>Chapter 2</td>
<td>Cephalometry Versus Roentgenographic Cephalometry.</td>
<td>13</td>
</tr>
<tr>
<td>Chapter 3</td>
<td>Assessment Errors in Lateral Roentgenographic Cephalometry.</td>
<td>17</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>Validity of Frankfort Horizontal as a Reference, Orientation and Superimposition Plane.</td>
<td>24</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>Soft Tissue Landmarks used in Measurement of Frankfort - Mandibular Plane Angle.</td>
<td>33</td>
</tr>
<tr>
<td>Chapter 6</td>
<td>Direct Measurement Instruments.</td>
<td>36</td>
</tr>
<tr>
<td>Chapter 7</td>
<td>Stability of the Lower Border of the Mandible.</td>
<td>43</td>
</tr>
<tr>
<td>Chapter 8</td>
<td>Significance of the Mandibular Plane Angle in Diagnosis.</td>
<td>47</td>
</tr>
<tr>
<td>Chapter 9</td>
<td>Observations Related to Mandibular Plane Inclination.</td>
<td>57</td>
</tr>
</tbody>
</table>
## Statement of Hypothesis

67

## Original Work

69

1. Method

70

1. Design

78

1. Construction

84

1. Application and Method of Use

85

2. Test Method Design and Implementation

88

2. Results

93

3. Discussion

107

4. Summary

113

5. Conclusion

115

6. Bibliography

118
LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Study of a man's head and skull, squared for proportion.</td>
<td>7</td>
</tr>
<tr>
<td>Figure 2</td>
<td>A horizontal reference line N-D is shown to intersect with M-G to form the facial angle Camper.</td>
<td>9</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Sliding caliper, spreading caliper, Todd Head spanner.</td>
<td>38</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Occlusal/mandibular plane angle measurement.</td>
<td>40</td>
</tr>
<tr>
<td>Figure 5A</td>
<td>Salzmann's maxillator adjusted to face, front view</td>
<td>42</td>
</tr>
<tr>
<td>Figure 5B</td>
<td>Salzmann's maxillator adjusted to face, side view</td>
<td>42</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Deep bite and open bite skeletal morphology.</td>
<td>46</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Hyperdivergence and hypodivergence of the facial planes.</td>
<td>53</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Muscle position in deep bite and open bite according to Sassouni.</td>
<td>61</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Under developed temporal and masseter muscles in open bite skeletal types and over developed temporal and masseter muscles in deep bite skeletal type.</td>
<td>61</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Mandibular goniometer, from patients side.</td>
<td>75</td>
</tr>
<tr>
<td>Figure 11</td>
<td>Mandibular goniometer, from observers side.</td>
<td>76</td>
</tr>
<tr>
<td>Figure 12</td>
<td>Cephalostat application of the instrument.</td>
<td>86</td>
</tr>
<tr>
<td>Figure 13</td>
<td>Chairside application of the instrument.</td>
<td></td>
</tr>
<tr>
<td>Figure 14</td>
<td>Correlation A:B</td>
<td>99</td>
</tr>
<tr>
<td>Figure 15</td>
<td>Correlation B:C</td>
<td>99</td>
</tr>
<tr>
<td>Figure 16</td>
<td>Correlation A:C</td>
<td>100</td>
</tr>
<tr>
<td>Figure 17</td>
<td>Correlation A,: C,</td>
<td>100</td>
</tr>
<tr>
<td>Figure 18</td>
<td>The radiographic image provided by technique B</td>
<td>106</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table I  Test method 1, technique A  95
Table II Test method 1, technique B  96
Table III Test method 1, technique C  97
Table IV Test method 1, techniques A,B,C.  98
Table V  Test method 2, ten readings by each technique, on one subject.  105

LIST OF DIAGRAMS

Diagram I  73
Diagram II  74
The significance of the mandibular plane angle has been of concern to clinical and Research workers in the field of Orthodontics, particularly as this profile angle could be observed clinically, photographically, and, with the advent of the Broadbent Cephalometer, with lateral cephalographs.

With the refinement and standardisation of Roentgenographic Cephalometry, other planes and landmarks were identified and less emphasis was placed on the diagnostic and clinical significance of this angle.

With current professional and public awareness of the level and cumulative effects of medical/dental short wave radiation, it is my desire to add to the revived interest by the orthodontic community in direct measure instruments and non invasive techniques, by designing, constructing, and testing an instrument to directly measure Frankfort-mandibular plane angle.

The literature indicates that direct measurement is as valid as most radiographic cephalometric analyses in determining lateral skeletal discrepancy. The design should incorporate features that, hopefully, are an improvement on earlier designs. To my knowledge there has been no reported testing of such earlier designs. However, an instrument of this nature if found to be accurate and reproducible, could be used ...

1. At the initial orthodontic examination, to assist in formation of a preliminary diagnosis.
2. As a teaching aid in orthodontics to alert students of mandibular plane inclination, and soft tissue landmarks at the clinical level.
That is, the instrument may act as a catalyst, to prompt further questions on mandibular morphology and inclination.

3. In craniometric studies, particularly in the field where portability of equipment is necessary.

4. In prosthetics and surgery to measure and establish pre-treatment and post-treatment mandibular vertical dimension.

5. Before, during, and after orthodontic treatment. The order of accuracy, however, would have to be established before credibility could be given in longitudinal studies of this nature.

6. As a "framework" to directly measure other facial angles, e.g. occlusal plane and soft tissue Na-Po.
LITERATURE REVIEW
1. ANTHROPOMETRY:

A BRIEF HISTORY OF CRANIOMETRY,

CEPHALOMETRY AND EARLY ROENTGENOGRAPHIC CEPHALOMETRY.
Craniometry, according to Finlay (1980), was defined in the Edinburgh Encyclopaedia of 1813 as "the art of measuring skulls of animals so as to discover their specific differences."

Cephalometry is concerned with measuring the head, inclusive of soft tissue in the living or dead, by radiographic or anthropometric means.

The dry skull has been measured from countless aspects for purposes of description and classification (craniometry). Craniostats were designed to hold the skull in an oriented position to give greater reliability to these measurements and they were the forerunners of the cephalostat or head holder. These static and non-vital studies did not hold much interest for most orthodontists and it was only after the measurements and relationships were applied to the living subject (cephalometrics) that their use in the field of Orthodontics was seen to be important (Allen, 1963).

The fifteenth century saw the advent of specific measurements being made to compare the features of different skulls and heads. According to Finlay (1980), Leonardo da Vinci (1452-1519), was probably one of the earliest people of note to apply the theory of head measurement to good effect in assessing proportions. He used a variety of lines related to specific structures in the head to assist in his study of the human form.

In Fig. 1 below, note that lines that correspond to those depicted on the skull, can be identified in addition to lines more appropriate to soft tissue anatomy.
Fig. 1

Study of a man's head and skull, squared for proportion.

(from Finlay, 1980.)
The most interesting line is that passing tangentially to the lowest point on the alar of the nose and the inferior aspect of the lobe of the ear. This line is close to horizontal when the subject is an upright posture looking toward the horizon. This is a recurring feature of many of the "base" lines that have been propounded since then, and very close to the modern Frankfort horizontal.

Finlay (1980), noted that Albrech Durer (1471-1528), used a similar horizontal for his base line. As an artist in 1528, he published a treatise on cranial measurements to aid his work. He investigated proportions of human form according to mathematical rules, this work being the first published attempt to apply anthropometry to aesthetics. This aspect of anthropometry has turned full circle with recent publications by R.M. Ricketts (1981, 1982), on the use of a "golden divider" to assess facial aesthetics.

Finlay (1980) and Neger (1959) noted that Pieter Camper (1722-1789) was concerned with the distinction of the racial differences and evolutionary changes in human faces. As illustrated in Fig. 2, below, Camper introduced a facial angle which he described as the intersection of a facial line (glabella to the alveolar margin of the upper jaw) and a horizontal (centre of the external auditory meatus to the wing of the nose.) This angle unfortunately ignores the contribution made by the lower jaw to facial form. Many early workers used a horizontal reference plane similar to Camper's plane thus enabling crude comparisons to be made between skulls.
Fig. 2

A horizontal reference line N-D is shown to intersect with M-G to form the facial angle of Camper.

(from Finlay, 1980.)
The Swedish anatomist Anders Retzius (1796-1860), provided the basis for the methods of craniology used today. He also devised the cephalic index, the ratio of breadth of the skull to length expressed as a percentage. (Finlay, 1980.)

John Barclay (1758-1826), was the first to incorporate the mandible into his measurements. Using a "goniometer" he measured the angle formed by "superior basifacial line" (similar to Camper's facial line) to the "inferior basifacial line" (lower border of the mandible.) The primary interest of these early anthropologists was the classification of cranial types according to race (Finlay, 1980.)

The nineteenth century saw the need to standardise craniometric methods. At the Anthropological Congress held in Frankfort-am-Maine in August, 1882, it was agreed to accept as a standard reference line the "horizontal" line introduced by Von Ihering in 1872, which was thereafter referred to as the Frankfurt horizontal plane. (Finlay, 1980.)

Von Ihering's plane passed through the centre of external auditory meati to the lowest point on the inferior margin of each orbit. The Frankfort agreement modified this definition so that the plane passed through the upper borders of the bony meati (left and right porion) and through the left orbitale only.

This can reduce the problem of assessing asymmetrical skulls. This convention applies today when, in Roentgenographic cephalometry, it is a frequent practise to use the image of the
orbit lying closest to the film for determining Orbitale (Gosman, 1950).

According to Allen (1963), and Krogman and Sassouni (1957, p.22), the Dutchman Van Loon, first introduced anthropology to orthodontics, using a plaster cast of the face, study cast of the dentition were inserted into the face cast for visual assessment.

Paul Simon, Milo Hellman, and others, adapted the techniques of physical anthropology to orthodontic research. Milo Hellman's technique consisted of using measuring instruments (spreading calipers, Todd Head spanner and sliding calipers) to measure soft tissue landmarks, using the Frankfort horizontal as a plane of orientation and produce a "profilogram" (similar to Bjork in his 1947 study) for lateral assessment and a "wiggle" gram (a forerunner of Vorhies and Adams, 1951), for depth, height and breadth assessment. His contributions in the 1920's and 1930's to the field of craniometrics and soft tissue cephalometrics and to the quantitative assessment of facial relationships provided a background to the methods used in present day Roentgenographic cephalometry. (Gosman, 1950).

In 1921, A.J. Pacini studied "Roentgenray Anthropometry of the Skull", believing that this procedure would be useful in the study of human development, classification and deviations. It was apparent, however, that standardisation of head location was important for accurate long term study.

B. Holly Broadbent worked with the anatomist T. Wingate Todd in the 1920's and, under Todds influence to "take the study of anatomy out of the dead house", Broadbent refined the craniostat
into a radiographic cephalostat to be used as a tool in the study of craniofacial growth. In 1931 he published "A New X-Ray Technique and its Application to Orthodontics". In the same year Herbert Hofrath published in the German literature, "Importance of Teleroentgenograms for Diagnosis of Jaw Abnormalities", soft tissue was of primary interest in his technique and Hofrath provided interest in his technique and Hofrath provided no means of superimposition of subsequent films. (Allen 1963, and Krogman and Sassouni 1957, p.24).

Roentgenographic cephalometry using the standardised Broadbent technique was further refined as a diagnostic tool available to the individual practitioner, methods of analysis developed, using internal and external mid saggital structures and the anthropometrical method of facial analysis in Orthodontics became less popular.
2. CEPHALOMETRY

VERSUS

ROENTGENOGRAPHIC CEPHALOMETRY.
Anthropometry and craniometry suffered a decline following the advent of Roentgenographic Cephalometry. Gosman (1950), admitted that operator knowledge of anatomical landmarks, correct handling of the measuring instruments to produce repeatable studies, are as much art as science. Gosman in his 1950 article "Anthropometric Method of Facial Analysis in Orthodontics", produced a clinical survey chart similar to Hellman, and using:

1. Sliding calipers to measure total face height.
2. Spreading calipers to measure bizygomatic width.
3. Todd head spanner to measure auriculo-menton distance, he compared the patients measurements to Hellman's "developmental stages" standard.

This standard is based upon the patients chronological age and dental development. This enabled Gosman to produce a "profilogram" i.e. a diagrammatic polygon representing the face in mid sagittal section. Treatment progress can be visualised by orienting the overlay upon the auriculo-nasion line. Using Hellman's standard IV for males, Gosman produced an angle of prognathism of 91.0°. Bjork in his 1947 study using Roentgenographic Cephalometry found this angle to average 90.8°. Gosman admitted that measurement errors are possible with the anthropometric technique but with practice this less bulky method could be adapted to office routine.

Moore and Lavelle (1974, p.9), felt that the digital computer may arrest the decline in popularity of craniometry by correlating the maze of statistics used in direct, or projected craniometry, to more accurately define the shape of structures as complex as those seen in the skull.
They felt a limiting factor had arisen from the realisation that many of the anatomical landmarks used in craniometry are subject to extensive remodelling. However, this is a problem common to any longitudinal study assessing bony landmarks.

Broadbent in 1931, stated that "the application of precise methods of measurement used by Physical Anthropologists to Orthodontic practice is a decided advance towards a more scientific solution to our orthodontic problems". However, he also felt that his radiographic technique had the advantage of not having to "determine the site of hard tissue landmarks of the face through the covering of soft tissue of uncertain thickness".

The correlation between Cephalometry and Roentgenographic Cephalometry was assessed by Jahina in 1961, and published in 1964. Jahina compared three Roentgenographic analyses (Northwestern, Down and Sassouni) with direct cephalometric measurement (anthropometry) on fifty white females in Hellman's stage IVA with C.II, Div. I, malocclusion, i.e. all permanent teeth except third molars had erupted. He used standard anthropometric landmarks and instruments in the direct survey and a Bolton-Broadbent cephalometer for the lateral cephalograms.

He found the Frankfort reference and orientation plane common to cephalometry and Roentgenographic Cephalometry and of great value for comparative study.

The results indicated that cephalometry occupied a central position among the four methods in terms of assessment of relationships, i.e. its overall agreement score was the highest, with the Downs analysis agreeing more with cephalometry than the other Roentgenographic analyses.
The highest agreement (94%-98%) of the four analyses was the mandibular plane to cranial base plane relationship, hence cephalometry alone told as much as Downs, Northwestern and Sassouni, about the mandibular plane to cranial base plane relationship.

Farkas and Cheung (1981), in an anthropometrical study of facial asymmetry in healthy North American caucasions, found a relatively low prevalence of asymmetry in the orbit-tragion (ex-t) distance in their study, suggesting that there is little variation in the location of the outer orbital landmarks in healthy faces.
3. **ASSESSMENT ERRORS IN LATERAL ROENTGENOGRAPHIC CEPhALOMETRY.**
The development of Roentgenographic Cephalometry created a need to accurately locate an increased number of landmarks on Roentgenograms. These landmarks can be used as registration points for measurement (angular and linear), as registration points for super imposition in linear growth studies, and also for planes of orientation.

Bjork (1947, p.34), and Baumrind (1971,b). described three reasons for error of method in cephalometric measurement studies.

1. Differences in the method of recording the image of an individual on separate occasions.
2. Differences caused by variation in locating and recording the landmarks.
3. Errors caused by the reading process.

Bjork considered that errors incurred by the reading process, in the case of measurements made from marked points, were negligible, and always of the same order.

Richardson (1966), investigated the variability in locating landmarks, investigated observer differences and measured the angular variation in lines and planes and found that while one observer could reproduce his measurements with an "acceptable" degree of accuracy, the discrepancies between measurements made by different observers were more serious.

Bjork (1947, p.35), made it clear that in lateral cephalometry, all angular and linear measurements are projections of the actual measurements onto the median or midsaggital plane.
This two-dimensional representation of a three dimensional object, will, in longitudinal studies fail to show significant changes of breadth.

Asymmetry of the facial skeleton and errors of projection (point source origin of anode beam) prevent the right and left halves of the mandible from co-inciding, the side closest to the source of radiation being relatively larger by approximately 5%. Bjork considered that tracing a median outline between the two images was acceptable.

Projection errors result from a linear photographic projection of an asymmetrical three dimensional head. A radiograph is not a photographic image, but a projected image from a point source. Diverging distortion occurs by foreshortening of distances between points lying in different planes, and by radial displacement of all points and structures not on the principal axis (the trans-meatal axis). The assumption that the trans-meatal axis is at right angles to the mid-saggital plane is not always valid as asymmetries can occur, complicating serial studies (Baumrind et al., 1971a, 1971b).

Baumrind et al assessed the reliability of head film measurements with three significant articles.

1. Landmark identification errors.

These are the errors involved in the process of identifying specific anatomic landmarks on films. From his results, Baumrind et al (1971a), drew three inferences.

a) Even when replicating assessments from the same head film, errors of landmark identification are too great to be ignored.

b) The magnitude of the error varies between landmarks.

c) The distribution of errors for each landmark is not random but systematic i.e. each landmark has its own characteristic and usually non circular "envelope of error".

The perceptual task involved in identifying landmarks is a function of:

i) How sharply the edge folds, in the region of the point being estimated i.e. sharp folds have good estimates e.g. incisal edges. Gradual curves, point A, point B, pogonion, menton and gonion are more variable and tend to be distributed along that edge.

ii) The degree of contrast to which the edge contrasts with the surrounding area i.e. low contrast indicates poor definition even in a "sharp" boundary e.g. the head of the condyle.

iii) Landmark definition.

On specific points, observer identification of machine porion, menton, orbitale and sella-tursica were fairly high. Nasion and gonion were lower on the scale, gonion because of broad curvature at the gonial angle and nasion often incurring gross errors as a result of identification of entirely different structures.
Richardson (1966) also found a "scatter" effect of curved point location but added that when this linear "scatter" occurs along the plane being estimated, (e.g. menton on the mandibular plane), errors are smaller. On the other hand, nasion is more reproducible for a vertically oriented plane such as the facial plane than a horizontally oriented plane, such as S-Na, because of its vertical "scatter". It therefore appears that machine point porion has a high identification accuracy and may therefore be finally more accurate than anatomic porion despite its soft tissue origin.

Baumrind strongly advises using replicated estimates for landmark location as head film estimates based on a single estimate cannot help but be flawed.

2. Conventional angular and linear measures.

Errors of projection and transmeatal head asymmetry can cause errors in angular and linear head measurements, however, angular measures are to be preferred, as values of angular measures remain constant despite the enlargement factor. Interestingly, angular measures not parallel to the mid saggital but projected onto this plane tend to make the measured angle more obtuse and never more acute. This error if of concern in mandibular plane measurement.

There are three considerations involving landmarks and angular values.

a) The actual magnitude of error involved in identifying the specific landmark.

b) The linear distance between the two points, i.e. in the case of angular measures, the closer together the points determining either line segment, the greater will be the

c) The direction envelope error e.g. menton in mandibular plane estimation.

Baumrind et al (1971b), found in their study that angular and linear measurement involves considerable errors and that errors tend to be greater for angular rather than linear measures. To be specific they could not ascribe clinical significance to a change in the Frankfort horizontal to mandibular plane angle of less than 3.6° and concluded "angular head film measurement is in most cases too inaccurate to differentiate all but the grossest change".

3. Tracing Superimposition.

Baumrind et al (1976), and Gravely and Benzies (1974), consider that tracing and superimposition errors are real and consequential, particularly in individual cases. In a conclusion to their study, Gravely and Benzies indicated that "even orthodontists with expert knowledge and years of experience had levels of tracing errors which make suspect the appraisal of a single cephalometric tracing".

Baumrind et al concluded that the operator should "refrain from making irreversible treatment decisions on the basis of small differences in any magic set of numbers". This theme was discussed by Hixon (1972), who indicated that researchers can use large sample sizes and computerized techniques to reduce variability in long term studies, Hixon discourages the use of Cephalometrics in general clinical practice for short term comparisons.
Hixon confines his use of Cephalometrics in a teaching situation to check changes in the lower incisor position.

Sucher and Laskin (1977), considered that the intraoral head holder of the cephalostat, by indirectly pressing on the mandibular condyle, caused an anterior positioning of the mandible. This would greatly affect our estimation of mandibular position.

Silling et al (1979), tested the validity of Cephalometric analysis at arriving at diagnostic and treatment planning decisions for various types of malocclusions. Twenty-four randomly selected orthodontists each evaluated six cases of malocclusion (two Cl.II, div.II, two Cl.I and two Cl.II, div.I), with the majority arriving at a satisfactory treatment plan in all cases, whether or not they had a cephalogram.

This study would suggest that certain types of malocclusion present obvious and reasonable solutions to the trained, experienced orthodontist and that the risk/benefit factor of ionising radiation has to be considered in diagnosis and treatment planning.

In conclusion, it appears that the errors involved in conventional cephalometry are subtle and considerable. As current orthodontic research seems to indicate a desire to establish non-invasive methods of diagnosis and observation (Burstone, 1982, Cooke and Tsang, 1982, Vig and Gurley, 1982), a more direct, less invasive technique to analyse facial form would be desirable.
4. VALIDITY OF FRANKFORT HORIZONTAL AS A REFERENCE

ORIENTATION AND SUPERIMPOSITION PLANE
Although Frankfort horizontal originally aided the orientation of dried skulls in craniostats, its valid transfer to the living as a horizontal orientation plane is doubted by some authors (Solow and Tallgren, 1971, Foster et al, 1981).

I intend to follow conventional terminology and use the term "Frankfort Horizontal" (FH) to refer to the intra cranial plane and not necessarily to its orientation.

1. Definitions:

a) A plane of orientation is one which aids the positioning of the head in space.

b) A plane of reference is one selected as a base for comparison when measurements are taken.

c) A plane of superimposition is a plane believed to be relatively stable during growth to which other less stable points or areas can be compared. Implicit here is the requirement of at least one fixed point. (Moore and Lavelle, p.18, 1974).

During Craniometry, Cephalometry and Roentgenographic Cephalometry, the FH has frequently been used for all three purposes. Stability is relative, the movement during growth of some point on the facial skeleton is usually described relative to a plane of reference, but it would be equally correct, to describe the plane of reference as moving relative to the facial landmark (Moore and Lavelle, p.19, 1974, Moyers and Bookstein, 1979).
2. Clinical Significance:

As a plane orientation, FH made an easy transition from Craniometry and Anthropometry to Roentgenographic Cephalometry. The early work of Hellman, Simon, Dreifus and Izard established the use of FH as a useful reference and orientation plane in the orthodontic office (Krogman and Sassouni, p.94, 1957).

Tweed (1946), through his treatment procedures and Downs (1948), in his assessment of antero-posterior facial relationships, confirmed the validity of FH. Downs (1948), tested his facial line (Na-P) to FH, SNa and the Bolton plane and found the reference plane FH provided the best measure of assessment of the facial angle. Downs (1948), and Ricketts (1975), agree that as a reference plane for changes in the maxilla and mandible, FH is preferable to the more remote S-Na.

Ricketts (1976), considers that as a plane of direct clinical communication, the external landmarks of tragus and soft tissue orbitale are unique in that they can be visualised clinically, photographically and correspond closely with bi-lateral bony landmarks-porion and orbitale that can be located radiographically. The significance of external landmarks was apparently not lost on Steiner, for, according to Broadbent et al (1975), he is reported to have stated "it is not Willies sella turcica that his mother is interested in, but his chin". The FH in upright man also tends to represent a horizontal to the earths surface. (Ricketts et al, 1976). In their summary, Krogman and Sassouni, (p.95, 1957), consider the FH "the best single plane of reference".
3. Anatomic and Growth forecasting considerations:

Ricketts (1972, 1975, 1976), considers that with porion in the temporal bone related to the semicircular canals and orbitale completing its slight downward movement at an early age, the FH has a direct relationship with the basic organs of hearing and sight. There is relative dependence in the behaviour of the maxilla to the upper face and to the anterior cranial base, however, Ricketts found little statistical correlation between the mandible and the anterior cranial base. This is indicated by the large variation found in the position of the glenoid fossae to S-Na. On the other hand, FH can serve as a reference plane for location of the glenoid fossae, its location is approximately in line with FH. Classification of mandibular position antero-posteriorly with reference to the cranial base has shown to be a weak method of facial typing (Downs, 1948).

Comparing FH and a pterygoid vertical with S-Na and a perpendicular through S as a Y axis, Ricketts (1976), considered the stability of these two planes for growth forecasting. In every instance the reference plane which utilized the FH was appreciably better than that which utilized s-Na.

This combination of FH orientation plane and a pterygoid vertical axis, formed a "polar" registration point about which growth appeared to radiate. Ricketts (1975), considered this to be a stable registration point from which to assess the maxilla and mandible. His research led him to the conclusion that the FH was the most useful and revealing plane of orientation for prediction and morphological description.
Measurement accuracy:

There are two factors to consider here:

a) Landmark identification.

b) Linear distance between landmarks.

a) Landmark identification.

Porion is strictly a craniometric landmark that has been transferred to Roentgenographic Cephalometrics via the ear rod locator on the cephalostat. Downs (1948), clarified this, by defining true or anthropometric porion as being located on the superior bony surface of the external auditory meati as distinct from a radiographic porion that is located on the highest point on the superior surface of the soft tissue of the external auditory meatus. A radio-opaque ear rod locator usually provides a good definition of soft tissue porion but can obscure bony porion. Krogman and Sassouni (1957, p.81), consider that the size and inclination (usually downward and forward), of the external cutaneous canal, can introduce considerable variability.

Ricketts (1976, 1981), and Richardson (1966), consider that bony porion is the key to correct posterior FH orientation as soft tissue porion can be up to 10 mm lower than bony porion. Baumrind (1971a), however, found a high observer landmark identification reliability attributable to machine point porion, this factor may override the problem that operators other than Ricketts have had in locating anatomic porion.

Orbitale similarly followed a craniometric definition of the lowest or deepest point on the inferior margin of the left
orbit, usually in the lateral half of the lower orbital margin (Krogman and Sassouni, 1957, p.82). This was modified for radiographic purposes by Bjork in 1947 to include the deepest mid-point on the infra-orbital margin when a double orbital image occurs. Baumrind (1971a), found a reasonable observer identification of orbitale.

b) Linear distance between landmarks:

Ricketts (1976), and Krogman and Sassouni (1957, p.311), agree that landmark identification errors involved in locating porion and orbitale, play a smaller role in the stability of the plane as the two cranial points are relatively distant from each other.

To summarize measurement accuracy, Ricketts (1976), tested the three planes S-Na, FH and Ba-N and found no statistically significant differences between the three, so that FH did not suffer from poor landmark identification and its location close to and more parallel with the mandible was a decided advantage.

5. Application in description:

Krogman and Sassouni (1957, p.311), consider that the more the reference plane is horizontal, the better it is for antero-posterior assessment. Ricketts (1976), compared statistically FH and S-Na with common anterior landmarks and concluded that for description antero-posterior deviations, "FH was the more reliable reference frame". Solow (1966), in comparing angular variables in young male adults considered that if the reference plane is closer to the plane being observed, its accuracy increases, further validating FH as a descriptive reference plane for mandibular assessment.
It is interesting to note that FH has an antero-posterior "freedom" not available to other reference planes using nasion. Use of the FH as a reference plane has involved a projection through FH e.g. Na-P, Na-A, thus any antero-posterior variability of porion and/or orbitale has no influence on the "projected" angular measure.

6. Relationship of FH to other intra and extra cranial reference lines.

a) Intra cranial reference lines:

Bell (1975), and Foster et al (1981), consider that a significant positive angular correlation exists between Frankfort and maxillary (ANS-PNS) cephalometric lines. Thus it is reasonable to accept the mean alignments of these lines as being parallel, but the range of variation for each is considerable. Tremont (1980), proposed the use of Sassouni's optic plane (the bisector of the supra-and infra-orbital planes), and Seal, (1964), the HIS line (ANS to Opisthion, the most posterior point on the foramen magnum). Each tested his planes against FH and found a high degree of correlation between the observed line and FH. That is for clinical purposes, FH, optic plane and the HIS line can be regarded as parallel. A suggestion was made that if doubt existed as to landmark identification of FH, then these two planes could be used to give confidence or support to FH.

b) Extra cranial reference lines:

Apparent discrepancies between "natural head posture", and intra cranial reference lines (particularly FH) led many observers to opt for "natural head posture", as a more reliable method of head location.

Natural head posture in the living was shown to be remarkable reproducible, the intra-cranial reference lines S-Na, FH and mandibular plane showing an apparent large variation, not so much to each other, as a true horizontal or true vertical. The suggestion was therefore, to use a natural head posture and a true horizontal or vertical in profile photographs or radiographs to more accurately assess dento-facial proportions and avoid the "biological variability" of intra-cranial landmarks, (Bjerin, 1957).

This observation is open to dispute. Bjork, (1951), indicated that the relationship of the cranial base to the facial form is often masked by the position of the head on the vertebral column. Solow and Tallgren, (1975), found a comprehensive set of correlations between craniofacial morphology and the position of the head in relation to the cervical column. Recently, Marcotte, (1981), found that individuals with prominent mandibles tend to tilt their forehead forward, conversely, people with retrognathic mandibles tend to tilt their forehead back; the individual appearing to "mask" the defect.
The studies by Marcotte, (1981), and Solow and Tallgren, (1975), thus give a valid reason for the apparent variability of intra-cranial reference lines.

Foster et al (1981), and Solow and Tallgren, (1971), using a natural head position, found a similar large variation of the observed mandibular plane angle (7° to 43°), it is therefore clear from these studies that clinical estimation of mandibular plane is inaccurate and that mandibular plane assessed against FH will eliminate postural errors.
5. **SOFT TISSUE LANDMARKS**

**USED IN MEASUREMENT OF**

**FRANKFORT-MANDIBULAR PLANE ANGLE.**
1. Porion:

This landmark made a transition from craniometry, where it is clearly seen, to anthropometry and then to Roentgenographic cephalometry. In anthropometry, for example, the Todd head spanner uses left and right soft tissue porions as locating points for mid-saggital measurement. Roentgenographic cephalometry uses soft tissue porion in conjunction with the head holder for orientation during the exposure.

Krogman and Sassouni, (1957, p.64), and Gosman, (1950), define soft tissue porion as the uppermost contour of the external auditory meatus. This is an instrument location and head location in the cephalostat can vary as the size and inclination of the cutaneous auditory meatus varies. Krogman and Sassouni, (1957, p.81), indicate that patient positioning can be standardised to minimise personal and instrumental error. This may, however, rely upon a personal technique that can vary between operators. It is therefore necessary to distinguish between the cutaneous external auditory meatus and true skeletal or bony porion. Ashley-Montagu, (1939), defines porion as situated at "the centre of the uppermost margin of the external auditory meatus and not a point which refers to any soft tissue structure of the head". He does acknowledge that the cutaneous external auditory meatus is a convenient locating point for anthropometric and radiographic studies and outlined a method of determining cranial porion. Vertically, the centre of the anterior helix was found to approximate the centre of the bony meatus. However, a more reliable method of locating true or bony porion is thus:
Select a point 2mm posterior and 5mm superior to the uppermost point on the roof of the cutaneous external auditory meatus. This will then locate true porion approximately using soft tissue landmarks. Using this located landmark, the average medial distance to true or bony porion is 9.6mm. This large soft tissue thickness would help explain the many variation seen in ear rod location.

2. Orbitale:

Orbitale can be defined as the lowest point on the lowest margin of the bony orbit determined by palpation. As a further aid to location, a point on the lower margin of the orbit, in line with the centre of the pupil of the eye looking straight ahead can be used.

3. Gonion:

Gonion, located by palpation, can be found at the point of greatest convexity between the posterior border of the ramus and the inferior border of the corpus at the angle of the mandible. Alternatively, the most lateral points at the angles of the mandible can be used.

4. Gnathion:

Gnathion can be defined as the most inferior point on the contour of the chin on the lowest medial point on the lower border of the mandible. This not bony Gnathion, it is nearer Roentgenographic cephalometric menton. (Krogman and Sassouni, 1957, p.64-65, Gosman, 1950).
6. DIRECT MEASUREMENT INSTRUMENTS.
These can be divided into:

1. Linear measure instruments.
2. Angular measure instruments.

1. Linear measure instruments:
   Commonly used instruments are:
   a) Measuring tape: a flexible steel tape, graduated in millimetres and used for measuring head circumference.
   b) Spreading caliper: used in the measurement of larger cranial distances, e.g. head height and head width.
   c) Sliding caliper: used for smaller linear distances, e.g. facial height.
   d) Head spanner: The instrument is located in the cutaneous external auditory meati and, using this "transmeatal axis", any point on the mid-saggital plane can be measured from this axis, see Fig. 3, below. (Gosman, 1950, Salzmann, 1957, p.147).

Eissasser, (1950), designed an instrument he termed a "facial Orthometer". This instrument, to be used in epidemiologic studies, measured the mid-saggital profile deviation of soft tissue landmarks from a standard index. Eissasser indicated that the low cost and portability of the instrument was an advantage over Roentgenographic cephalometry in mass surveys. Ricketts, (1981, 1982), proposed the use of an instrument he termed a "golden divider". This instrument does not provide a direct linear measure, but produces a constant proportion of 1:1.618, this ratio is found to be related to human aesthetic appreciation. Facial proportions using obvious soft tissue landmarks, e.g. alar of nose, stomion, gnathion, that
Fig. 3

Sliding caliper, spreading caliper, Todd head Spanner.

(from, Gosman, 1950).
approximate this "golden ratio", are said to be aesthetically pleasing and functionally optimal.

Recently, Cooke and Tsang, (1982), described and tested a metal linear measure instrument that related lower incisor position to soft tissue A-Po. The correlation of the direct measure readings to lateral radiographs was only moderate, and, anterior overbite may prevent incisor tip location. However, it was suggested that the instrument could prove useful when radiographic facilities are limited.

2. Angular measure instruments:

The measurements made in anthropometry may be direct, or projected. A direct measurement is made along the shortest distance between and two anatomical landmarks, and applies to most linear measure instruments. Aboul-Ela and Abdel Rasek, (1977), Neger, (1951), and Savitz, (1948), designed instruments to measure the Frankfort-Mandibular plane angle (FMA), paralleling their instrument along the lateral border of the mandible. Due to the obliquity and variability of the measured angle compared to the mid-sagittal plane, errors of angular measurement are introduced, these errors are variable if the mid-sagittal plane is not used for reference. Instruments of this design therefore have a reduced value in comparative study with lateral radiographs of the skull. The instrument designed by Aboul-Ela and Abdel Rasek, (1977), is illustrated in Fig. 4, below.

Salzmann, (1945, 1957, p.148), described in detail the construction and use of an instrument he termed a "Maxillator", to measure the FMA, gonial angle and mandibular incisor angle. Using a soft issue FH from tragion to orbitale, a sliding base with a protractor was used to measure the FMA.
Fig. 4

Occlusal/mandibular plane angle measurement.
(From Aboul-Ela and Abdel-Rasek, 1977).
The instrument was visually aligned with the patient’s mid-sagittal plane thus producing a more useful comparative projected measure. (See Figs. 5A and 5B below). Salzmann suggested that his instrument be used as an aid to orthodontic diagnosis and classification, in outlining and planning treatment, to monitor changes during treatment, as an aid to fixed or removable prosthesis construction and finally, in craniometric studies. The accuracy of these instruments compared to lateral radiographs is not known. The four instruments described, however, use a flat mandibular base piece, this would produce a variable mandibular plane reading due to the varying convexity of the lower mandibular border, and it is doubtful if their order of accuracy was clinically useful.
Fig. 5A
MAXILLATOR ADJUSTED TO FACE. FRONT VIEW

Fig. 5B
MAXILLATOR ADJUSTED TO FACE. SIDE VIEW

Salzmann's Maxillator
(From Salzmann, 1945).
7. **STABILITY OF THE LOWER BORDER OF THE MANDIBLE.**
Bjork, (1969, 1972), in his implant studies, found that assessment of the rotation progression of the mandible is complicated by a compensatory remodelling of the lower border. A forward rotation seems to be a general feature of facial development and, as a broad rule, about one half of the rotation that occurred in the corpus is masked by lower border remodelling. Nanda, (1971), found that the mandibular plane reduced by an average of 1° every three years during a twelve year growth period. However, there was an acceleration of the rotation during the pubertal growth spurt. Bryant, (1981), noted that in cases of forward rotation, remodelling is marked by apposition below the symphysis and anterior part of the lower border, leading to a convexity in this area, while resorption below the gonial angle leads to a flattening in this region. According to Bjork, (1969), the characteristic form of the remodelling provides a better indication of growth direction than its inclination. (See Fig.6, below).

Thus:

1. Pronounced antegonial notching and lower border concavity is associated with backward rotating condyles and a tendency to open bite.

2. Absence of antegonial and the presence of lower border convexity is associated with forward growing condyles and a tendency to deep anterior overbite. (Bjork, 1969, Sassouni, 1969).

Haskell, (1979), found that the chin (protuberantia mentalia), increases in size as the mandibular type varies from vertical type to a normal type, to a horizontal type of growth pattern.
He considered that his study supported the concept that chin form in man may be the result of compensative growth developing in response to the most structurally efficient jaw form.

Lower border resorption is compensatory but predictable and, to the clinician, inclination of the lower border is the one clear diagnostic aid available. Ricketts, (1981), clarified the rate of mandibular rotation, his value of FMA of 28° ± 4° at three years reducing 1° each three years to maturity (i.e. 21° at age twenty four years), is fairly close to the age related values found by Taylor and Hitchcock, (1966), Broadbent et al (1975), and Bishara, (1981).

It is interesting, here, to include the thoughts of Thurow, (1975, p.21). "The variation in dimension and proportion in these structures (muscles of mastication, mandible and airway), is greater than will be found in almost any other part of the body in persons generally accepted as normal". Implicit here is a function/form relationship to be considered primarily in terms of respiratory requirements and secondarily in terms of mastication, speech and deglutition.
Fig. 6

Deep bite and open bite skeletal morphology.
(From Bjork, 1969).
8. SIGNIFICANCE OF THE MANDIBULAR PLANE ANGLE IN DIAGNOSIS.
"Other than overbite correction, few orthodontists give vertical changes any consideration in their case analysis". Creekmore, (1967), thus indicated a greater professional concern with antero-posterior profile changes than with changes in the vertical dimension. Schudy, (1964), also concluded that "the vertical dimension is the most important dimension to the clinical orthodontist and that vertical dysplasias are inseparable related to both open and closed bites". It appears, that unlike antero-posterior discrepancies, the vertical dimension has to be considered in terms of both anterior and posterior facial height. Bjork, (1969, 1972), further clouded the issue by describing the effect of the direction of condylar growth on mandibular rotation as a factor introducing variability of the lower border as a reference plane. Schudy, (1964), Haas, (1980), Johnson, (1950), and Ricketts, (1981), generally agree, that the mandibular plane represents more than anything else, the vertical height of the ramus. The mandibular plane has thus fallen in and out of favour, as a descriptive reference plane for vertical discrepancies.

Sassouni and Nanda (1964), considered that vertical facial disproportions were the origin of many antero-posterior disharmonies. The statistical relationship of vertical growth and a steep mandibular plane angle and horizontal growth with shallower mandibular plane angles was confirmed by Lundstrom and Woodside (1981).

With regard to Roentgenographic lateral assessment, Sassouni and Nanda, (1964), proposed the use of the Sassouni archial analysis as an accurate method of differential diagnosis of facial types.
Haas, (1981), recommended the Downs and original Ricketts analysis. He proposed that their use together, will locate antero-posterior and vertical dental dysplasias and, combined with a study of mandibular morphology, should provide a sound basis for diagnosis.

The significance of the mandibular plane in diagnosis will be discussed with particular reference to the thoughts of V. Sassouni, F. Schudy, C. Tweed and E. Johnson.

V. Sassouni.

Sassouni, (1969), stated that one of the objectives in orthodontic diagnosis is to distinguish between malocclusions and skeletal disproportions. He suggested that nomenclature used to describe antero-posterior disproportions (Class I, II, III), be used in conjunction with nomenclature developed and used to describe vertical disproportions (open bite, deep bite). According to Sassouni, facial types are associated with functional and familial characteristics that should be included in a comprehensive diagnosis. He described the characteristics of skeletal "deep bite" and skeletal "open bite".

**Skeletal deep bite:**
1. Hypodivergence of the supra orbital, palatal, occlusal and mandibular planes, i.e. these planes are nearly parallel.
2. Concave profile.
3. The masseter and internal pterygoid muscles are attached anteriorly on the mandible. The molars are directly under the impact of these vertically directed masticatory forces. The anterior component of force is also reduced.
4. Anterior and inferior position of the glenoid fossae.
5. Small gonial angle. The gonial processes maybe flared laterally, indicating strong masseter action.
6. Convex lower border of the mandible.
7. Total posterior height (sella to gonion) nearly equal to total anterior facial height (supra orbital to menton).
8. A tendency to be brachycephalic.
10. Broad palate.
11. Reduced tooth size with a tendency to increased abrasion and reduced arch crowding.
12. Adequate pharyngeal space, i.e. tongue thrusting seldom seen.
13. Excess of lip height, relative to face height, with a tendency towards a sub labial furrow.
14. Forward mandibular rotation.

**Skeletal open bite:**
1. Hyperdivergence of the lateral reference planes.
2. Convex profile.
3. The posterior vertical chain of muscles are "arcuate", and well behind the molar resistance, this, together with diverging palatal and mandibular planes, creates a pronounced anterior component of force.
4. Superior and posterior position of the glenoid fossae.
5. Total posterior face height tends to be one half of the size of the total anterior face height.
6. A tendency to be dolicocephalic.
7. Narrow nasal aperture.
8. Narrow palatal vault.
9. Large tooth size with a tendency to bilateral dental protrusion, crowding, and reduced abrasion.
10. Reduced pharyngeal space with a tendency to tongue thrust.
12. Large gonial angle.
13. The lower border of the mandible tends to display antegonial notching and a tendency to be concave.

F.F. Schudy.

Schudy, (1964, 1965), focused on the relative development of the anterior and the posterior face height. The critical factor appears to be the proportionality of vertical development between the condyle-fossa areas on one hand and the maxillary, sutural, alveolar and dental processes on the other. If molar vertical growth equals condyle-fossa vertical growth, the mandible can then grow downward and forward in a linear, translatory fashion. When vertical growth in the molar region is exceeded by growth in the condyle-fossa area, forward rotation results. Conversely, relatively less condyle growth causes a backward rotation of the mandible with the fulcrum occurring at the molar region (Schudy, 1965, Bryant, 1981).

Schudy (1964, 1965), proposed the SN-Mp1 angle as a measure of facial divergence, indicating that the predominantly horizontal reference planes are the best indicators of vertical variations. He added, that as the face grows, two to three times as much vertically as anterio posteriorly, vertical assessment is logical for facial typing and proposed the terms "hypodivergence"
and "hyperdivergence" to express facial depth and facial height. These terms refer to the degree of divergence of the mandibular, occlusal, palatal and SN planes to each other. (See Fig. 7 below).

His 1964 study indicated that statistical validity of the mandibular and occlusal planes in classifying morphological and functional types. He criticises the "Y" axis as being not sensitive enough in assessment of the vertical dimension, "the Y axis merely tells us where the chin is in relation to the cranium, but does not tell us by what route it travelled to arrive there". Schudy reminds us that this "race" between anterior and posterior face height for stability is finally won by the condyles, as the condyles are usually the last portion of the facial complex to stop growing, especially in the males. This factor is most important in understanding the post treatment "return" of the mandibular plane angle.

C.H. Tweed

Charles Tweed, (1946) studied the F.M.A., as it related to orthodontic treatment objectives, post retention stability, and facial aesthetics. Through Tweeds, work, the mandibular plane angle, became a frame of reference for planning, criteria were established to place planned extractions on a rational base, and, in the words of Herbert Margolis, (1945). "This Frankfort mandibular plane angle will serve as a guide and a red light when discussing prognosis prior to treatment".

Prognosis assessment.

1. Tweed considered the normal FMA range to be between 16° and 28° with 60% of all malocclusions falling within this range.
Fig. 7

Hyperdivergence and Hypodivergence of the facial planes.
(From Di Pietro and Moergeli, 1976).
He considered prognosis to be excellent near 16° to good near 28°
2. From good at 28° prognosis progressed to fair of 32°
3. From fair at 32° prognosis was considered not favourable at 35°.
4. Above 35°, orthodontic treatment with or without extractions was contra indicated.

Tweed suggested that assessment of the FMA can be made using:
1. Salzmann's "Maxillator" and directly measuring the patient.
2. Tracing and measuring a lateral head radiograph.
3. Tracing a profile photograph.

In 1954, Tweed considered visual assessment of the FMA to be inaccurate, he stated that in 40% of cases, the error of assessment was between 3° and 11°, when compared to lateral radiographs.

Although he assumed growth to be constant (translatory) and geared his mandibular plane classification to edgewise mechanics, Tweed's observation of the mandibular plane demonstrated the practical application of anthropometric measurement of the dento facial area to the every day practice of orthodontics.

**E.L. Johnson.**

Johnson, (1950), in the first significant study of the mandibular plane angle from a statistical base, surveyed 150 lateral radiographic head films and related the facial pattern to the mandibular plane angle. After grouping the radiographs into four areas according to Tweed (1945), he noted "a very marked and consistent increase in lower face height", an increase in the vertical growth of the alveolar process, retroclination of the lower anteriors and an increase in the gonial angle as the FMA increased.
He considered, the relatively low angle cases (less than 25°), displayed a separate and distinct facial type, mainly because of his finding a larger vertical length of ramus, than in other groups. He concluded the the FMA was a valuable diagnostic criterion in the analysis of the facial pattern in orthodontic patients.

Recently, Bishara and Augspurer, (1975), and Di Pietro and Moergeli (1976), discussed the role of the mandibular plane inclination to orthodontics and prosthetics respectively. Bishara concluded, that the cant of the mandibular plane could assist in identifying facial types, but should not be used alone, in diagnosis and classification. The implication here, is, as Sassouni, (1969), indicated, that antero posterior disproportions and vertical disproportions should be considered as two basic growth directions that interact, producing a "resultant" of mandibular growth that reflects the individuals particular growth characteristic. As Bishara and Augspurer, (1975), indicated, the mandibular plane and the facial type, are the result of the cumulative effect of various genetic and environmental factors acting during the development of the individual.

In considering genetic mandibular influences, Moss and Salentijn, (1971), found for example, the vertically growing open bite mandibles were associated with "specific spatial and developmental abnormalities of the oral functioning space". They found, that large mandibular plane angle cases, had stable mandibular landmarks that characteristically occupied a "low" portion of a logarithmic curve. The implication is that this genetic characteristic is established early and is dominant, and that any
observed tissue changes are secondary and compensatory.

Various environmental influences were discussed by McNarmara, (1981), as having an effect on the vertical development of the mandible, e.g. abnormal muscle function, altered occlusal interdigitation, altered respiratory function and altered mandibular posture.

It is difficult to establish clear genetic or environmental dominance in mandibular plane inclination. However, certain environmental associations have been linked with the vertical dimension. These can be assessed by the clinician, and, together with measurement of mandibular plane inclination, assist in understanding functional considerations in orthodontic diagnosis.
9. OBSERVATIONS RELATED TO MANDIBULAR PLANE INCLINATION.
It is difficult to separate cause from effect. However, extremes of mandibular plane inclination have been investigated and linked with certain functional and morphological characteristics that should serve as a guide, and perhaps a warning in orthodontic diagnosis and treatment. The mandibular plane has been used widely by clinicians to express intuitive perceptions about the relationship of function to form, (Ricketts, 1981).

1. The mandibular plane and normal occlusion:

A general guide to normal mandibular plane inclination is to regard an FMA angle of $25^\circ \pm 5^\circ$ as average for early adolescence. As Nanda, (1971), indicated, there is great variability of this angle at all ages. However, it is reasonable to assume that "High angle" patients have FMA inclinations above $30^\circ$ and "Low angle" patients have FMA inclinations below $20^\circ$. (Di Pietro and Moergeli, 1976).

Christie, (1977), studied the radiographic cephalometric pattern of adults with normal occlusion and found that the skeletal framework surrounding this ideal occlusion was more likely to be brachyfacial than dolichofacial, and the mandibular plane inclination averaged at $19^\circ$ to the Frankfort plane. Christie considered that brachyfacial characteristics (flat occlusal plane, low FMA, broad arch form), were more conducive to a normal, stable dental pattern. The implication is, that the more brachyfacial a patient is, the greater is the likelihood that they can be treated non extraction, because of the greater available arch length. Christie considered that this finding had profound implications in treatment planning, as a diagnostic classification according to the Cephalic index should temper extraction considerations.
2. Facial Typing.

Cephalic Index = \( \frac{\text{maximum head breadth} \times 100}{\text{maximum head length}} \)

- Above 80% = Brachycephalic
- 75 - 80% = Meso cephalic
- Below 75% = Dolichocephalic

(Salzmann, 1957, p.148)

High mandibular plane angles are associated frequently with anterior open bites, vertically growing facial patterns, long narrow (tapering), arch form and dolichocephalic head proportions.

Low mandibular plane angles are associated with deep anterior overbite, horizontal growth patterns, broad arch form and brachycephalic head proportions. These associations are not rigid but assist in classification, (Sassouni, 1969, Lundstrom and Woodside, 1981, Graber, 1972, p.209). It appears that the cephalic and facial indices relate to each other and for orthodontic purposes can be assessed subjectively. (Krogman and Sassouni, 1957, p.170).

3. Functional associations of extreme mandibular plane inclination:

a) Bite force.

Sassouni, (1969), and Di Pietro and Moergeli, (1976), cite the work of Paolini who studied the relationship of bite force to facial type. He found that male deep bite skeletal type individuals, generated a significantly greater maximal biting force than male open bite skeletal types. The mean bite force found for the extreme open bite sample measured at the molars was 142.8 pounds, while the mean for the extreme deep bites ample was 229.4
pounds. Other studies tend to substantiate this claim. Ingervall and Thilander, (1974), Moss, (1975), Ringquist, (1973), and Pancherz, (1980), found the activity in the temporal and masseter muscles during maximal bite varied with the inclination of the mandible, the activity increasing with the facial types that have a tendency to parallelism between the jaw bases, i.e. low mandibular plane angles. Sassouni and Nanda, (1964), in linking form to function, suggested, that in high angle cases the vertical masticatory chain of muscles exert an oblique force posterior to the molar resistance, increasing the anterior component of force but decreasing the occlusal force on mastication. In low angle cases, the vertical masticatory chain is perpendicular and, more anteriorly situated, "thus exerting its major force against the molars". (See Fig. 8, below).

Ricketts, (1981), considers that conjectures about "weak" and "strong" mandibles have led to the wide use by clinicians of the mandibular plane angle as a key diagnostic factor to relate structure and function to treatment mechanics.

b) Tongue posture:

Sassouni, (1969), suggested that the pharyngeal space is restricted in a high mandibular plane, open bite configuration. This would require a forward tongue posture to establish pharyngeal patency. Conversely, in deep bite, low angle types, the pharyngeal space is large, the tongue is set posteriorly and is seldom associated with forward posture or "thrusting". The relationship between "tongue thrusting", tongue posture and the mandibular plane angle has been studied by a number of authors.
Fig. 4. (Left) The skeletal deep-bite type of patient. "The molars are directly under the impact of the masticatory forces of this chain." (Right) The skeletal open-bite type of patient. "The posterior vertical chain of muscles is arcuate, and the masseter is posterior to the molars and premolars."

Fig. 8

Muscle position in deep bite and open bite according to Sassouni.
(From Di Pietro and Moergeli, 1976).

Fig. 9

Under developed temporal and masseter muscles in open bite skeletal types and overdeveloped temporal and masseter muscles in deep bite, skeletal type. (From Sassouni, 1969).
Ballard, (1965), Spiedel, et al, (1972), considered that in many high mandibular plane angle patients, the tongue frequently postures forward in order to establish an anterior oral seal. Ballard, (1965), in particular, noted that the higher the mandibular plane angle, the lower was the dorsum of the tongue in relation to the hard and soft palates. These factors have considerable clinical significance in establishing the aetiology of high angle, dento-alveolar relationships. Tulley, (1964), in his study of tongue thrust incidence in school children noted the high incidence of a large mandibular plane angle in his hospital tongue thrust sample. Smernoff, (1965), in a preliminary study of tongue thrusting and mandibular morphology found that "patients characterised by an open bite and tongue thrust tend to have very steep mandibular planes".

Thurow, (1975, p.22), considers that forward tongue posture in high angle cases is associated with a demand by the geniohyoid muscle to contract and maintain pharyngeal patency. He claims that the geniohyoid is almost in a continual state of contraction in these cases, its pull "effectively opening the mandible". This occurs because the survival requirement of respiration takes precedence over mastication.

c) Naso-respiration:

Mc Namara, (1981b), cites a study by Linder-Aronson relating airway resistance to facial type. He noted that children with long narrow faces have greater nasal resistance on the average than those with short, wide faces. The same author in 1970 showed that one of the characteristics of patients requiring adenoidectomy was a steep mandibular plane angle.
Mc Namara (1981b), also cited a study by Quick and Gundlach on 113 orthodontic patients that found naso-pharyngeal impairment on 63% of high angle patients and only on 23% of low angle patients. Rubin, (1980), considers that by the age of four years, the cranio-facial skeleton has reached 60% of its adult size and by age twelve, when orthodontic treatment is about to begin, 90% of facial growth has occurred. He reasons that the orthodontist should react to problems related to vertical facial growth and high mandibular plane angles earlier and relates many of these vertical dysplasias to infant feeding patterns producing allergic sensitisation and partial respiratory obstruction.

Animal studies have shown a change in the mandibular plane angle with variations in respiratory resistance. Mc Namara (1981b) quotes a study by Harvold on young rhesus monkeys that showed an increase in the mandibular plane angle with increased nasal obstruction. Linder-Aronson, (1975, p.100), noted a strong correlation between increased nasal resistance and an increase in the mandibular plane angle. The functional nature of the mandibular plane angle is indicated by a reported reduction of the mandibular plane angle in children who had undergone adenoidectomy. Similar conclusions were reached by Subtelny, (1980), and Dunn, et al, (1973), indicating that naso-pharyngeal obstruction is related to changes in mandibular inclination, thus supporting the concept that functional and environmental factors are important determinants of facial morphology.

d) Speech:

Tipnis, (1971), studied the association of FMA with interdental "s" sounds, 1,436 cases were examined and it was noted
that patients with Cl II, div. I, malocclusions had the highest incidence of "interdental s" sounds. This grouping also had the highest incidence of high FMA's. "Only one Cl II, div. I, case had a interdental s sound in combination with a low FMA, it would appear therefore that interdental s occurs with the greatest frequency in the Cl II, div. I case and often together with a high FMA". It thus appears that the incidence of "interdental s", increased in cases with a high FMA.

e) Head posture:

Using natural head posture, Solow and Tallgren, (1971), found that the mandibular and other craniofacial planes displayed a high variability compared to a true vertical. Bjerin, (1957), found a similar result and reasoned that the cause was a great biological variation in the location of the base planes. Solow and Tallgren (1971), found that the inclination of the mandible was of the same order as the cervical column and concluded "these findings may reflect interrelationships between the facial morphology and the head balancing mechanism." When this concept was followed up by Solow and Tallgren in 1976, their studies indicated that the position of the head in relation to the cervical column was found to display "a comprehensive set of correlations with craniofacial morphology".

Extension of the head in relation to the cervical column was found in connection with:

I. Large anterior and small posterior facial height.
II. Small naso-pharyngeal space.
III. High mandibular plane angle.

Flexion of the head was seen in connection with:
I. Small anterior and large posterior facial height.

II. Large naso-pharyngeal space.

III. Low mandibular plane angle.

They suggested that functional factors such as respiration, swallowing and speech might be involved in mediating this relationship between head posture and craniofacial morphology.

Marcotte, (1981), cites a further study by Solow and Tallgren, that suggests that head posture is influenced by respiratory resistance and it will change once that resistance is reduced. Vig et al, (1980), studied the manipulation of head posture by experimentally increasing nasal resistance on test subjects. Total nasal obstruction resulted in a progressive extension of the head in 1½ hours, head position returned to the pre-obstruction level after the removal of the obstruction.

Marcotte, (1981), studied the relationship between head posture and dentofacial proportions, and, found that of all cephalometric measurements studied, the position of the mandible showed the strongest correlation with head posture. "For those individuals who had a steep mandibular plane angle ... there is a significant tendency for the face to be elevated with the forehead angled back". These changes suggest that posture alteration is an adaptation to naso-respiratory requirements.

f) Occlusion:

Di Pietro, (1977), studied the relationship between the FMA and naturally occurring occlusion groups in 112 subjects. The mean FMA's for the occlusion groups showed a progressive increase from disclusion or canine protection (19.6°), to group
function (28.9), i.e. in low angle cases, canine protection is the norm, and in high angle cases, group function is the norm. Di Pietro suggested that FMA determination in diagnosis and treatment planning procedures is vital in understanding the relationship of structure to function in occlusion.

Mc Norris, (1979), and Fowler, (1982), discuss this interesting concept by relating the steepness of the eminence to the occlusal plane. They state that the closer the plane of occlusion parallels the anterior border of the eminence, less posterior tooth separation occurs, this condition occurs as the mandibular plane becomes steeper. The reverse function applies to low angle cases, as the divergent anterior eminence/occlusal plane ensures posterior disclusion.
STATEMENT OF HYPOTHESIS
The direct measurement, in the living, of the Frankfort-mandibular plane angle, by use of a mandibular goniometer either hand held, employing an operator assessment of the patients mid-saggital plane, or by employing machine location of mid-saggital, is as valid and reproducible, as lateral Roentgenographic Cephalometry in assessing this angle.

Further development of this instrument could provide direct assessment of both vertical and horizontal facial proportions, dental and skeletal, and may eventually replace lateral Roentgenographic cephalometry, in the orthodontic clinic.
ORIGINAL WORK
1. METHOD
In order to test the hypothesis, a mandibular goniometer to directly measure FMA was constructed which, hopefully, would overcome the limitations apparent in other designs. The design limitations of the other instruments as perceived by the author are:

1. Lack of orientation of the instrument to an acceptable reference plane. e.g. mid-sagittal.
2. Lack of rigidity of the instrument material.
3. A disregard of varying lower border morphology in the mandibular section.

With these earlier design limitations in mind, my method involved:

1. Design and construction of a measuring device that would prove:
   a) Reproducible and reliable at direct measurement of FMA over a wide range of angles.
   b) Aesthetically and functionally acceptable to operator and patient.
   c) Capable of direct chairside orientation but also capable of orientation in a cephalostat.

2. Design and implementation of a test method to determine within observer reproducibility and validity of the instrument. Fortunately, due to the aesthetically acceptable, non invasive nature of the instrument, unlike radiographic studies, it lends itself well to a reproducibility study.
MANDIBULAR GONIOMETER

Information to be used with diagrams I and II:

Material : Transparent cast sheet and rod acrylic.

Main frame thickness : 6.0mm

Diameter of menton and gonion locators : 20.0mm

Diameter of porion locator : 9.0mm reducing to 6.5mm.

Threaded rod : 10.0mm

Menton locator length : 90mm

Gonion locator length : 40mm

Overall height : 168mm

Overall length : 140mm

Overall weight : 250gms approximately.

Scale : 1:2

N.B. for clarity, porion locator was omitted from diagram I, and gonion locator from diagram II.

Although the diagrams are to one half scale, detailed dimensions are not included as the diagrams are intended to indicate component design and overall proportion only.
Fig. 10
Mandibular goniometer, from patients side.
Fig. 11

Mandibular goniometer, from observers side.
DESIGN, CONSTRUCTION AND METHOD OF USE.
DESIGN

In selecting the mandibular plane for measurement, it was considered that while the lower border of the mandible is partly involved in the facial profile at the symphysis and menton region, towards the gonial angle, observer estimation is often flawed. (Downs, 1956, Foster, et al, 1981). This may be due to variations in musculature (phenotype), and variations in subcutaneous fat. (Sicher, 1975, p.409), Parnell, (1958, p.32 and p.34), noted that puberty was a difficult time to measure skinfold thickness due to early pubertal disturbances in subcutaneous fat. His diagrams also imply that predominantly mesomorphic and predominantly ectomorphic individuals have approximately the same skinfold thickness, with only predominantly endomorphic individuals having a noticeably higher skinfold thickness.

The design of the instrument was thus considered with this problem in mind, plus perceived design flaws of earlier instruments and an overall philosophy of being aesthetically acceptable to the patient, easy to operate and "non invasive". Soft tissue landmarks were identified relating to the FMA and adjustable "locators" were constructed to reach these soft tissue landmarks. The locators project out at right angles from a two part sliding main frame that incorporates a protractor.

Material:

The complete mandibular goniometer was constructed from cast sheet and rod acrylic (polymethyl methacrylate). This material possesses a flexual strength at rupture of 1,050 kg/cm/cm and a flexual modulus of elasticity of 3 x 10,000 kg/cm/cm.
This makes it "stiffer" than the nearest comparable thermoplastic material, "lexan" (polycarbonate), and thus less liable to flex when loaded. Unfortunately this acrylic has a heat distortion temperature (at 264 p.s.i.), near the boiling point of water, thus eliminating normal water based sterilization procedures.

Optically, it has a light transmittance rate of 93% which makes the material as clear as rock crystal. Its specific gravity of 1.19 means that compared with inorganic glass, cast acrylic is less than half of its weight. It is non toxic to human tissue, can be sawn, turned, threaded, sanded, buffed and cemented. It is insoluble in inorganic chemicals and normal chained hydrocarbons (i.e. 95% ethyl alcohol, Sodium hypochlorite), but contact with organic solvents (e.g. Ethyl acetate, carbon tetrachloride and benzene), will cause partial dissolution of the material. It has a coefficient of thermal expansion of 7 x 10 cm/cm/°c, (7 to 8 times that of iron), but this is not considered to be a problem, considering the environment in which the instrument will be used and the stable nature of angular as compared to linear measures. Its surface hardness is similar to that of aluminium making it harder than other plastic sheet, but a little softer than glass. (Technical Handbook for "Shinkolite A", by Mitsubishi Rayon Company, using ASTM test procedures).

The cementing material (Acrifix- 92), consisted of a colourless, viscous, partly polymerized acrylic resin, its polymerization completing under the influence of long wave ultraviolet rays. After polymerization its strength is 75% that of the original material.
The two part main frame was constructed from 6mm sheet acrylic. The menton and gonion locator rods were constructed from acrylic rod 20mm in diameter. These sizes were considered adequate to cater for normal loading without plastic deformation, i.e. short term loading during clinical use. Stress for a longer period causes deformation due to "creep" of the material. Therefore the instrument should be stored flat when not in use. Acrylic was also selected for its radioluscency.

Landmark selection and locator design:

Criteria for landmark selection:

a) External.

b) Palpable.

c) Conform to standard anthropometric and cephalometric definitions.

d) Capable of unambiguous observer identification in the living subject.

e) Not prone to injury during instrument use.

Porion:

Soft tissue or cephalometric porion was selected as being the highest point on the superior surface of the soft tissue right side external auditory meatus. A porion locator was constructed of 9mm diameter rod tapering to 6.5mm at its location in the meatus.

Orbitale:

With the above criteria in mind the author decided to select the lateral canthus of the right eye as a readily identifiable landmark and relate this point to orbitale. Ricketts, (1972, 1981), suggested that as the lateral canthus of the eye averages 15mm
above the top of the ear rod, (soft tissue portion), joined to the lateral canthus or lateral angle of the eye will approximate the Frankfort plane. As observer palpation and location of orbitale is prone to error and a constructed locator rod would hover dangerously close to the pupil of the eye, orbitale was selected at the lateral canthus of the eye. A "sighting line" was incorporated on the top of the instrument. The top of this line was located 15 mm above the top of the ear rod locator (soft tissue portion), and extends to the lateral canthus of the eye. This "sighting line" locates orbitale laterally and visually and is safer in use. This line then becomes an assumed Frankfort plane. It is quite probable that not all orbits are of the same dimension. However, this Frankfort plane satisfies the original criteria for landmark selection. This line maybe more accurate than selection of bony orbitale through soft tissue for, as Baumrind, (1971a), made clear, landmark identification is the foundation for accurate cephalometric measurement.

Gnathion:

(menton)

Krogman and Sassouni, (1957, p.64), indicated that this soft tissue landmark is the most inferior point on the contour of the chin, it is not radiographic gnathion but is closer to radiographic menton. Thus location of the most inferior point of the soft tissue chin locates radiographic menton. This point together with the postero-inferior border of the mandible as a landmark, constitutes the mandibular plane as defined by Downs, (1948), and used in this study.
Skin thickness at this region may vary with the level of subcutaneous fat and even the inferior fibres of the musculus mentalis as they pass the lower border of the mandible to end in the skin on the inferior surface of the chin, (Sicher, 1975, p.154, p.411). A locating rod 20mm in diameter was constructed to locate menton.

**Gonion:**

Krogman and Sassouni, (1957, p.65), indicate that this point is located by palpation as the point of greatest convexity between the posterior border of the ramus and the lower border of the mandible. It is however an old craniometric landmark of the mandible, often measured transversely with calipers, (Gosman, 1950). It is thus difficult to locate laterally, so I have accepted the advice of Baumrind, (1971a), and followed the definition of Downs, (1948), to locate "gonion" at the postero-inferior border of the mandible.

Sicher, (1975, p.411), indicates that the posterior inferior border of the mandible can readily be palpated through the skin, the muscles of mastication appear to insert just short of the inferior border. Again a locating rod of 20mm in diameter was used to locate "gonion". The author considered using a flat platform. However, the theoretical consideration of equal soft tissue indentation using two rods of the same diameter was thought preferable as they were capable of approaching the bony landmarks equally.

It is applicable to note here that the instrument in measuring FMA is searching for a bony landmark and that soft tissue points identified in the subject are only a guide to the location of the bony points. Therefore soft tissue landmark identification, locator indentation and soft tissue thickness are important
variables in the location of the bony mandibular plane.

The menton and gonion locators and the Frankfort sighting line provide for horizontal and vertical adjustment. The porion locator has provision for horizontal and lateral adjustment.

Orientation:

The instrument is designed to measure from the right side of the face only. This is a convenient position at the chairside and avoids the error involved in asymmetrical bi-lateral landmarks. The right side of the face is also the side closer to the film cassette in the lateral cephalograph as used in this clinic and is thus the side subject to the lesser magnification and distortion.
CONSTRUCTION:

The main frame, Frankfort sighting line, and mandibular base piece incorporating the protractor were constructed from 6mm cast sheet acrylic. Various designs of these three components were used, the final design being the lightest, most convenient to hand hold and yet provide the necessary rigidity in measurement.

The protractor used was 150mm in diameter and provided an angular measurement range of 0° to 55° to within 0.5°. The central angular focus of the protractor co-incides with the central axis of the threaded portion of the menton locator and along the upper most side of the locator.

The threaded rods and knobs were machined from 9mm, 22mm and 41mm acrylic rods from working plans. All necessary unthreaded parts were glued and cured upon assembly of the instrument. A vertical line on the main frame provided a reference line for the protractor, the protractor was reversed from its normal reading position to provide the smallest practical separation from the main frame reference line to minimize parallax error.

Two similar instruments were constructed, only one of these was used in the experiment to avoid possible differences in angular readings. The vertical reference line on the main frame and one degree "markers", on the protractor were outlined with radiopaque Barium Sulphate and 0.18" (.46mm), circular ligature wires were placed at the extremities of the menton, gonion and porion locators. These "markers" were designed to provide a radiographic record of the protractor and instrument landmarks during the proposed radiographic application of the instrument.
APPLICATION AND METHOD OF USE

Application:

The intended application of the instrument is for clinical use in the dental chair with an observed estimation of the patient's mid-saggital plane. For test purposes however, an additional technique was designed to provide machine orientation of the instrument to more accurately locate the patient's mid-saggital plane.

Method of use: Technique of measurement.

CHAIRSIDE: Operation estimation of mid-saggital plane.

a) It is preferable to have the patient upright, with the head located in a head rest, teeth together (centric occlusion), lips together, eyes open and looking straight ahead.

b) The ear rod is firmly located and adjusted into position laterally but left with horizontal "freedom".

c) Menton locator is then moved vertically and located in the correct anatomic position.

d) The superior edge of the Frankfort sightline is aligned with the lateral canthus of the eye and, at the same time, porion locator is locked into position.

e) The mandibular base is rotated until the gonion landmark is reached (usually just posterior to the palpated antegonial notch). Fine adjustment is carried out with the horizontal adjustment of the gonion locator.

f) With the operation satisfied with, mid-saggital orientation, landmark identification and registration, the locking knobs are then tightened, the instrument removed and the angular reading taken.
Fig. 12 Cephalostat application of the instrument.

Fig. 13 Chairside application of instrument.
CEPHALOSTAT: Machine orientation of the instrument to mid-sagittal plane.

An acrylic arm was constructed to replace the right side head holder arm of the cephalostat. This arm was provided with a horizontal slot that enabled the instrument to be locked into position, both ear rods then being "machine aligned". The main frame of the instrument was then located at right angles to the ear rod (trans-meatal) axis.

A method similar to the chairside technique was used to register the angular measure.
TEST METHOD DESIGN AND IMPLEMENTATION.
Two test methods were designed to determine the reproducibility and validity of the instrument using two "techniques", of direct measurement. These were then compared to two angular measures recorded from one standardised lateral radiograph of each patient.

Direct measurement method - technique A:

As described previously, this technique is the usual method of recording FMA at the chairside with an observer estimation of the patients mid-saggital plane. This is the most convenient technique. However, observer orientation of the instrument may introduce errors.

Direct measurement method - technique B:

An angular measure is taken in the cephalostat so that the instrument and the patients mid-saggital plane are approximately parallel. This technique involves machine orientation of the patients head and the instrument, and, as this method reduces at least one variable, it is possibly more accurate, but less convenient than technique A.

Radiographic measurement method - technique C:

One standardised, lateral skull radiograph was taken of each patient at the time of recording either measurement A or B. Right side radiographic landmarks relating to the FMA were recorded on 0.06mm acetate tracing film on a viewing box with a standardised light source. The tracing was drawn with a 0.25mm technical pen for maximum contrast and uniformity of the line thickness. The angular measure was read with a 150mm protractor and readings were taken to the nearest 0.5°.
Right side landmarks recorded:

1. Cephalometric menton - this is a readily identifiable midline landmark.

2. Gonion - this was taken to be postero-inferior border of the mandible, posterior to the ante-gonial notch, on the smallest, highest image, when they did not coincide.

3. Porion - the uppermost point on the smallest ear rod circle, when they did not coincide.

4. Orbitale - the most inferior point of the smallest, highest, or least laterally dispersed image, when they did not coincide.

Test method 1.

This consisted of a double determination study on 24 subjects. Each subject was measured twice using technique A, and twice with technique B, with the time interval between technique readings being one week. Two separate tracings and angular measures were recorded from each patient's radiograph, (technique C). The second tracing and measurement was performed one week after the first tracing.

The double readings from techniques A, B and C were recorded. The average deviation, mean of the differences, standard deviation and, dependant "t" values were calculated.

It was decided that a mid point between the first and second readings would be valid as a representative measure for comparison between techniques. The techniques were then compared in the ratio A:B, B:C, A:C.
To determine the relationship of the techniques, correlation, intercept on the Y axis, and slope calculations were performed. To test the difference of the techniques from zero (the null hypothesis), independent "t" values were calculated.

Test method 2.

This reproducibility study consisted of ten separate measurements of one subject using each technique. That is, at one "sitting", with techniques A and B, the patient was measured ten times, the instrument landmark locators being "neutralised", between readings. Ten tracings of the one radiograph were drawn and measured, as previously described on separate occasions.

The mean, standard deviation, coefficient of variation and standard error of each technique was found and "t" tests (independent), were performed between the techniques in the ratio of A:B, B:C, A:C., to determine if their difference was statistically significant from zero.

Test method 3.

The test instrument was designed to leave a radiographic "trace" at each landmark when set up and radiographically recorded in the cephalostat. Technique B therefore would be recorded as a radiographic image and the position of the locators assessed visually on the film to determine the error between the bony landmarks and the locators. A lateral radiograph illustrating this test method is included for interest only, as this radiographic technique did not lend itself to a reproducibility study.

N.B. The measurements in the three test methods were observed and recorded by one observer with the patient in centric occlusion,
all measurements relate to the right side of the patient's face only. To remove any possibility of the observer being influenced by previous readings, white removable labels were used to obscure the angular readings of the instrument during instrument location in techniques A and B.
2. RESULTS
Test method 1.

The two angular readings taken on 24 subjects using techniques, A, B and C are listed in tables I, II and III, respectively. The paired readings, and, a mean for each pair of readings in each technique are listed.

Table IV is a listing of these means for each pair of readings in each technique. This table provided a method of testing the statistical significance of the difference between the groups and their correlation. A graphical representation of these readings together with the correlation, slope, and intercept on the Y axis for A:B, B:C, A:C, A::C, are listed in figures 14, 15, 16 and 17, respectively.
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<td>G.T.</td>
<td>30.5</td>
<td>31.5</td>
<td>+1.0</td>
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<td>16.0</td>
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<td>20.0</td>
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</tr>
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<td>26.0</td>
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</tr>
<tr>
<td>9.</td>
<td>D.B.</td>
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</tr>
<tr>
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<td>J.P.</td>
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<td>26.0</td>
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<td>28.0</td>
<td>0.0</td>
</tr>
<tr>
<td>18.</td>
<td>K.B.</td>
<td>36.0</td>
<td>36.0</td>
<td>0.0</td>
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<td>B.R.</td>
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<td>-0.5</td>
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<td>D.L.</td>
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<tr>
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<td>J.W.</td>
<td>37.0</td>
<td>36.0</td>
<td>-1.0</td>
</tr>
<tr>
<td>24.</td>
<td>R.Q.</td>
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<td>28.0</td>
<td>-0.5</td>
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</table>
TABLE IV

Test method 1.

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<thead>
<tr>
<th>subject</th>
<th>Technique A</th>
<th></th>
<th>Technique B</th>
<th></th>
<th>Technique C</th>
<th></th>
</tr>
</thead>
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<tr>
<td></td>
<td>mean</td>
<td>d</td>
<td>mean</td>
<td>d</td>
<td>mean</td>
<td>d</td>
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<tr>
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</tr>
<tr>
<td>6. J.V.</td>
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<td>29.2</td>
<td>+0.7</td>
</tr>
<tr>
<td>7. L.B.</td>
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<td>21.7</td>
<td>+0.2</td>
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<td>8. K.P.</td>
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<td>-0.5</td>
</tr>
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<td>-2.0</td>
<td>19.7</td>
<td>-1.3</td>
</tr>
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<td>+3.2</td>
<td>30.7</td>
<td>+4.5</td>
</tr>
<tr>
<td>11. M.M.</td>
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<td>32.5</td>
<td>+1.7</td>
<td>34.2</td>
<td>+4.2</td>
</tr>
<tr>
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<td>-0.5</td>
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<td>27.0</td>
<td>+0.8</td>
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<td>+0.2</td>
</tr>
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<td>+0.2</td>
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<td>+0.7</td>
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<tr>
<td>17. B.N.</td>
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<td>+1.0</td>
<td>28.0</td>
<td>+5.5</td>
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<tr>
<td>18. K.B.</td>
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<td>34.5</td>
<td>+1.5</td>
<td>36.0</td>
<td>+3.0</td>
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<td>19. N.M.</td>
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<td>32.5</td>
<td>-1.7</td>
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<td>+0.5</td>
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<td>-0.2</td>
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<td>36.5</td>
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<tr>
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<td>30.0</td>
<td>-1.8</td>
<td>28.2</td>
<td>-0.8</td>
</tr>
</tbody>
</table>
**FIG. 14.**

A : B

\[ r = +0.97 \]

slope = \(1.01\)

intercept = \(+0.47^\circ\)

**FIG. 15.**

B : C

\[ r = +0.94 \]

slope = \(1.10\)

intercept = \(-2.46^\circ\)
FIG. 16

$A : C$

$r = +0.93$

$slope = 1.13$

$intercept = -2.29^\circ$

FIG. 17

$A_1 : C_1$

OMITTING D-W.

$r = +0.94$

$slope = 1.04$

$intercept = -0.08^\circ$
Table I.

<table>
<thead>
<tr>
<th>Average Deviation</th>
<th>= 1.14°</th>
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</thead>
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<tr>
<td>Mean of Differences</td>
<td>= +0.06°</td>
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<tr>
<td>S D (n-1)</td>
<td>= 1.42°</td>
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</tbody>
</table>

Table II.

<table>
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<th>Average Deviation</th>
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</thead>
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<td>Mean of Differences</td>
<td>= 0.04°</td>
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<td>= 1.31°</td>
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</table>

Table III.

<table>
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<th>Average Deviation</th>
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<td>Mean of Differences</td>
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</tr>
<tr>
<td>S D (n-1)</td>
<td>= 0.82°</td>
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</table>

"t" tests, assuming dependence were calculated on the first and second readings in tables I, II and III. In each case, the "t" values were less than 0.20, so it can be assumed that the differences between the first and second readings were not statistically significant (p. >, 0.20).

Table IV.

<table>
<thead>
<tr>
<th>A:B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean A</td>
</tr>
<tr>
<td>Mean B</td>
</tr>
<tr>
<td>Mean C</td>
</tr>
</tbody>
</table>
correlation  \( r \)  =  +0.97  (significant \( p.<, 0.001 \)).
intercept on Y axis  =  +0.47°
slope  =  1.01
t (independent)  =  0.51  (not significant \( p.>., 0.20 \)).

That, is the difference between A and B, is not statistically different from zero.

B:C

correlation  \( r \)  =  +0.94  (significant \( p.<, 0.001 \)).
intercept on Y axis  =  -2.46°
slope  =  1.10
t (independent)  =  0.29  (not significant \( p.>., 0.20 \)).

A:C

The twenty four paired readings were termed A:C.
Twenty three readings omitting D.W. were analysed and termed 
\( A_1 : C_1 \). It was considered that this one large difference \( 9.3° \). may have influenced the correlation factor, slope and the intercept.

A:C

correlation  \( r \)  =  +0.93  (significant \( p.<, 0.001 \)).
intercept on Y axis  =  -2.29°
slope  =  1.13
t (independent)  =  0.76  (not significant \( p.>., 0.20 \)).

\( A_1 : C_1 \),

mean \( A_1 \)  =  26.15°
mean \( C_1 \)  =  27.10°
correlation \( r \) = +0.94 (significant \( p.<, 0.001 \)).

intercept on Y axis = -0.08°
slope = 1.04
t (independent) = 0.12 (not significant \( p.>., 0.20 \)).

Test method 2.

Ten readings on one subject using the three techniques are listed in table V.

technique A

mean = 25.65°
standard deviation = 0.53°
coefficient of variation = 2.1 %
standard error = 0.17°

technique B

mean = 27.55°
standard deviation = 1.17°
coefficient of variation = 4.2 %
standard error = 0.37°

technique C

mean = 27.70°
standard deviation = 0.26°
coefficient of variation = 0.9 %
standard error = 0.08°
A:B

t (independent) = 4.6 (significant p.<, 0.001).

B:C

t (independent) = 0.4 (not significant p.>, 0.20).

A:C

t (independent) = 10.1 (significant p.<, 0.001).

Test method III

An example of the radiographic image provided by the instrument as set up in technique B is given in Fig. 18.
TABLE V

TEN READINGS BY EACH TECHNIQUE ON ONE SUBJECT.

Test method 2.

<table>
<thead>
<tr>
<th></th>
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<th>Technique B</th>
<th>Technique C</th>
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<td>28.0</td>
</tr>
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</tr>
<tr>
<td>3.</td>
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</tr>
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</tr>
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<td>26.0</td>
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<tr>
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<td>27.5</td>
</tr>
<tr>
<td>9.</td>
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<td>27.0</td>
<td>27.5</td>
</tr>
<tr>
<td>10.</td>
<td>25.0</td>
<td>27.5</td>
<td>28.0</td>
</tr>
</tbody>
</table>
Fig. 18

The radiographic image provided by technique B.
3. DISCUSSION.
In order to discuss the results appropriately, the parameters of the study need to be kept in mind.

i.e. 1. One observer.

2. Twenty four subjects not according to sex, age or FMA.

3. The particular test analyses employed.

4. One instrument design only, was developed and tested. The particular instrument design was developed from design deficiencies of other similar instruments, as perceived by the author, and does not necessarily represent the optimum design.

The mean of the differences with regard to sign, as observed from tables I, II and III was very close to zero. This indicates that the one variable of this aspect of the study, namely the one week time interval between measurements, did not influence the direction of the difference. That is, although a difference was observed from the first to the second reading, this difference was not biased in any particular direction in the group.

The paired readings of technique A (Table I), produced a SD of 1.42°. This technique as used at the chairside, has the problem of visually aligning the instrument to the patients mid-saggital plane. It is understandable, therefore, that the SD of this technique (1.42°), would be higher than that produced by technique C (0.82°), is possibly explained by the use of right side landmarks only when tracing the cephalograph, and, the use of only one cephalograph for each patient.
Technique A is of most interest in a practical sense, as this technique can be readily applied at the chair side to find the patients FMA. The SD of 1.42° compares favourably with the measurement error (SD) in lateral cephalometry of 1.81° found by Baumrind, et al, (1971b), and 2.1° to 3.3° found by Gravely and Benzies, (1974).

When considering one subject as in test method 2 (Table V), the SD at the chair side was 0.53°. That is, in this particular subject, landmark location at the chair side was relatively easy, resulting in a smaller SD than that provided by the paired readings of twenty four subject in Table I. "t" values in table V of A:B, A:C, showed that their difference was statistically significant and B:C not statistically significant. The "t" values of the comparisons A:B, A:C, B:C, in table IV were not statistically significant. An explanation for this is that for this one particular subject, the mean of the readings in technique A (25.65°), when compared with the mean of the readings in techniques B and C (27.55° and 27.70° respectively), together with small standard errors produced this statistical significance. That is, this one subject read consistently high in the radiograph and the cephalostat but consistently lower in the chair. The means of the group readings as in Table IV, (A=26.48°, B=27.27°, C=27.78°), are much closer, as most individuals had closer readings for between technique comparisons.

The means of the readings of technique A in methods 1 and 2 are lower than the means of the readings of techniques B and C in methods 1 and 2.
In one possible explanation for this, Sutcher and Laskin, (1971), considered that the intrameatal head holder of the cephalostat may effect an anterior positioning of the mandible. However, it is also reasonable to assume that, at the chairside, observer estimation of the patients mid-saggital plane is prone to error, seemingly in one direction, i.e. the measured angle is lower than radiographic or cephalostat technique.

The difference between the mean of techniques B and C in methods 1 and 2, (.51° and .15° respectively), indicates a slight but consistent increase in the radiographic FMA. One explanation for this is a difference or error in the location of the protractor in the instrument when compared to the tracing protractor. Another explanation is that the point source radiation beam from the anode maybe recording menton on the film in a slightly inferior position to its true position.

If consideration is given to the parallel nature of the locating rods on the instrument as set up in technique B, then these parallel rods maybe a physical representation of an ideal parallel radiation beam, resulting in a truer location of menton. This is the furthest landmark used in this study from the film and from the axis of the radiating beam at porion. A radiograph of the instrument was taken as set up in technique B but without a patient. This was traced twice and the radiographic image of the instrument was found to be 1-2 degrees higher than the actual instrument reading. Future testing of an instrument of this nature may then be used to measure the difference between the true and the radiographic position of three dimensional landmarks.
The radiographic image provided by technique B is illustrated in Figure 18. Figure 18 shows reasonable menton and gonion locator positioning. Gonion is slightly anterior to its ideal position and the Frankfort sighting line is slightly tipped up at the posterior.

A most important aspect of the instrument however, is the correlation of the radiographic image angle to the direct measure technique angle. An ideal direct measure mandibular goniometer may or may not produce the same angular reading as a lateral cephalograph. It would however be capable of reading low to high angles with equal "error", and, produce a slope characteristic of 1:1. Any consistent "error" would be recorded as a correction factor on the Y axis to be applied to the instrument reading to equate it with the radiographic reading. The representative readings in Table IV when applied in the paired comparisons, of A:B, B:C, A:C, produced high positive correlations. The slope of 1:01:1 for A:B was close to the "ideal", however B:C, A:C were a little further away from the "ideal" (1.10:1, 1.13:1, respectively). This alteration of the slope from the "ideal" produces a non uniform direct measurement error when compared to the radiograph. (See Figs. 14, 15, and 16). A₁: C₁ compared the A and C columns of table IV but omitted the readings of D.W. It was considered reasonable to omit this one large difference (9.3°), and test the remaining twenty three readings.

This is illustrated in Fig. 17. A:C relationship is important as it represents the angular relationship of the chairside use of the instrument to the radiographic image. A₁: C₁ was closer to the "ideal" with a slope of 1.04:1 and an intercept on the Y axis of close to zero.
Fig. 17 could be used in a clinical situation to relate lateral radiographic norms to a direct measurement of FMA at the chairside.

In its clinical use, the instrument appears sensitive to the observer location of the lateral canthus of the eye. That is, if the subject looks up, then the angular reading is "high", conversely, if the subject looks down, then the angular reading is "low". Landmark location by palpation on the lower border was straightforward. Correct location of the instrument following palpation, however, was a little more difficult. Although skin marking is aesthetically undesirable, its use would assist in accuracy of instrument placement.

It thus appears that although the instrument produces individual variations, its use at the chairside seems valid, reproducible, and compares well with the measurement error of clinical lateral Roentgenographic cephalometry.
4. SUMMARY
A mandibular goniometer to be used to directly measure FMA, was designed, constructed, tested and compared to the lateral Roentgenographic image of this angle. Two test procedures were used to analyse the readings.

One test procedure used twenty four subjects not selected according to age, race or sex. Paired readings in each of the two direct measure techniques and the one radiographic technique were used to find the statistical significance within and between techniques. Correlation, slope and intercept values were calculated between techniques to establish their relationship. No statistically significant difference was recorded within or between techniques. High positive correlations and close to 1:1 slope values were obtained between techniques, indicating a uniformity of instrument reading over a wide range of angles.

Another test procedure on one subject can be regarded as an individual finding, in that, although the chairside technique was found to produce statistically different readings when compared to a radiographic image, the individual variations, within the technique were less.

It appears therefore, that although landmark and mid-saggital location, and soft tissue thickness, are considerable variables, direct measurement of the FMA with this instrument by this observer, compares well with the measurement error of FMA in clinical lateral Roentgenographic cephalometry found by other authors.
5. CONCLUSION
1. Lateral Roentgenographic cephalometry with its invasive nature and measurement error maybe inappropriate at the clinical level.

2. A mandibular goniometer was designed, constructed and tested in an attempt to establish an alternative method for measuring FMA that maybe appropriate at the chairside.

3. This preliminary study established that an instrument of this nature appears to be valid and reproducible in clinical use.

4. Further testing should involve:
   a) More subjects grouped according to sex and age. They should be selected to include a wide range of mandibular slopes in order to further test validity and reliability of the tool.
   b) Different designs and different materials to be tested on a similar test method to determine optimum design and material.
   c) Many observers.

5. The comment by Baumrind, et al, (1971b), that "our current measurement instrument, the angular head film measurement, is in most cases too inaccurate to differentiate all but the grossest changes" may equally apply to the mandibular goniometer as tested here.

6. In teaching, prosthetics, surgery and in the orthodontic clinic, the instrument appears to be valid and reproducible in establishing the FMA. However, at this stage of development, conventional short term post treatment changes would probably be too small to differentiate.
7. The author did envisage a removable platform to be fitted to the menton locator of the instrument to be used, in conjunction with the FMA measurement, to measure the FH to "occlusal plane" angle. This acrylic platform would be used to locate the maxillary incisal edge and the maxillary first molar permanent cusps, could then be used to orientate study models. These trimmed models, when placed on a flat table could then be used to "visualize" the cant of the patients occlusal plane related to the horizontal provided by the table and the patients FH. This would give the clinician more information relating to the vertical dimension than current trimming procedures.

Thus normal chairside diagnostic procedures, knowledge of the patients FMA and FH/"occlusal plane", trimmed study models, would assist the clinician in the analysis of form (gestalt), non-invasively.

8. To conclude, instruments of this nature represent technology that is:

   a) Valid
   b) Reproducible
   c) Portable
   d) Relatively inexpensive
   e) Available, at the clinical level
   f) Non-invasive
   g) Aesthetically and functionally acceptable to both patient and operator.
Addendum:

The specific conclusion that can be drawn from the test procedures used in this study is:

This observer found that the reading error found in direct measurement of F.M.A. at the chairside to be within the measurement error found in estimating F.M.A. in lateral radiographic cephalometry.


