6. CEPHALOMETRIC ASSESSMENT OF MANDIBULAR INCISOR POSITION

6.1. HISTORICAL REVIEW

6.1.1. CEPHALOMETRIC MANDIBULAR INCISOR ASSESSMENT

Radiographic cephalometry was first introduced into orthodontics in 1930s when Broadbent and Hofrath simultaneously and independently developed cephalostats to produce cephalometric radiographs in a standardised manner. (Krogman and Sassouni, 1957, p24; Allen, 1963; Moyers, 1988, p250) The method, however, really gained wider acceptance for practical application from the 1950’s. Over the years a whole range of analyses has been developed by a number of clinicians. Although they vary in their general approach to measurement (linear, angular or graphical comparison with a template), the basic goal of diagnostic cephalometric analysis can be summarized as evaluation of relationships of the five major functional components of the face: the cranium and cranial base, the skeletal maxilla, the skeletal mandible and the maxillary and mandibular dental arches. (Khouw et al, 1970)

Of these functional relationships, the accurate assessment of the relative position of the dental arches in their respective jaw bases has been considered to be an important area of diagnosis. Furthermore, the proper positioning of the lower arch is thought to be more important in aiding a functionally stable occlusion than the maxillary arch. Angle (1907, p25) considered the mandibular arch as the form over which the maxillary arch should be moulded. The position of the lower arch in turn is determined by the position of the lower labial segment and thus the lower incisors were regarded by many as the key area of diagnosis and treatment.
evaluation.
(Steiner, 1953; Tweed, 1954; Downs, 1956; Lindquist, 1958; Berger, 1959; Ricketts, 1960 a; Williams, 1969)
"The angulation and position of the mandibular incisors sometimes determine the course and type of treatment patients receive." (Metzdorf, 1977)
As a result, much attention has been focused on the antero-posterior position and inclination of the lower incisors, from the point of view of their effect on the profile and the stability of the treated result. These considerations dictated the desired incisor position and inclination, from which extraction and anchorage requirements were assessed and orthodontic mechanics planned.
In order to meet these basic requirements of profile aesthetics and stability, mean values of the angle of long axis and the position of the lower incisors in relation to various cephalometric reference lines have been used as guidelines for incisor position and inclination, but it has been found that a stable result could not be predicted by using any of the published reference lines. (Schulhof, 1977)
Angle (1928) recognized the axial position of the individual tooth to be critical in orthodontic treatment, but it was Tweed (1941) who first gave the lower incisor axial inclination the individual attention it now enjoys. He emphasized the position and inclination of the lower incisors as a prime factor to be considered in diagnosis and treatment planning. He proposed that the most stable and aesthetic results were obtained when the lower incisors were placed upright over the basal bone of the mandible. His concept of the "diagnostic triangle" which relates the lower incisor to the mandibular plane and Frankfort horizontal plane was evolved over many years from observation of changes achieved in tooth positions and in particular, lower incisor positions which gave rise to desirable facial aesthetics.
With the introduction of Tweed's concepts, there arose a new interest in the mandibular incisors and the ramifications of their position in treatment of malocclusion.

Cephalometric norms for the angular and linear positions of the lower incisor have since been studied repeatedly. (Edwards, 1968)

Krogman and Sassouni (1957) listed 22 analyses by various authors providing norms for lower incisor position in relation to some cranio-facial line or plane.

Noyes, Rushing and Sims (1943) related the lower incisor axis to the mandibular plane which were drawn tangent to the two most inferior points on the lower border of the mandible. In their sample of 23 normal occlusions the mean angle was 90.7 degrees.

Margolis (1943) also related the lower incisor axis to the mandibular plane and reported that the angle formed by the mandibular plane and the lower incisor ranged from 90 to 93 degrees. He stated that for the vast majority of white children the best results were obtained when the lower incisors are 'vertical' and form a right angle with the mandibular plane.

Brodie (1944) also looked at the lower incisor-mandibular plane angle in a sample of 104 cases made up of Class I, Class II div.1 and Class II div.2 malocclusions. Although his findings were similar to the previous studies, there was also a large range of values and thus he noted the inadequacy of this measurement as a basis for clinical judgement.

Speidel and Stoner (1944) again measured the lower incisor mandibular plane angle in 42 adult males with superior to ideal occlusions, and found a mean value of 93.64 degrees with again a fairly large range.

Higley (1945) noted that, although the lower incisor-mandibular plane angle was
useful, the position of the lower incisor in relation to the chin point was more important. This was supported by Corlett (1947) who measured in 452 patients, the distance from the lower incisor to a line tangent to pogonion at right angles to the mandibular plane. The mean position of the lower incisor was 8 mm behind this reference plane.

Margolis (1947) examined 100 children aged 6-19 years with excellent occlusion and the mean lower incisor-mandibular plane angle was found to be 90 degrees with a S.D. of 3 degrees. He also related the lower incisor to the facial plane (N-mental eminence) which on average intersected the lingual surface of the lower incisor crown.

Downs (1948) examined 20 children with excellent occlusion, ranging in age from 12 to 17 years. He related the lower incisors to upper incisors, mandibular plane and to the occlusal plane and found angular means of 135.4, 91.4, and 75.5 degrees respectively.

He was the first to evolve a total cephalometric analysis which considered both skeletal and dental relationships. This made significant contributions to the practical application of cephalometrics in clinical orthodontics and has become the foundation for many subsequent cephalometric analyses.

Tweed (1954) analysed a sample of 100 untreated patients selected on the basis of good facial profiles. He related the lower incisors to the Frankfort horizontal plane and found a mean value of the Frankfort-mandibular incisor angle (FMIA) of 65 degrees. It was also found that there existed a compensatory relation between the mandibular incisor- mandibular plane angle (IMPA) and the Frankfort-mandibular plane angle (FMA).

Steiner (1953) made the first attempt to relate the lower incisors to the facial
environment through NA and NB lines. He found that the mean lower incisor-NB angular and linear measurements were 25 degrees and 4 mm in front of the NB line respectively. He suggested that the lower incisors be measured both with linear and angular measurements, thereby attempting to compensate for irregular angular changes in the incisors which are produced by root apical movement.

According to Steiner, the position of the lower incisors was individualized according to the patient's projected dental base discrepancy as measured by the angle ANB, and the relative prominence of the bony chin. The acceptable lower incisor position was determined from measurements, ANB, L1-NB and NB-Pog, and the range of values for lower incisor position with varying ANB angles was termed 'acceptable compromises'. This method of lower incisor assessment, therefore, assumed that no single mean position was appropriate and took into account the guiding effect of the ANB angle and chin configuration. The possible effect of the vertical skeletal relationship, however, was not considered.

Downs (1956) first related the lower incisor to the A-Pog line. However, he attached little diagnostic significance to this line of reference in assessing lower incisor position.

Holdaway (1956) and Ricketts (1960 a), however, recognised the significance of this line and advocated use of the line in locating the final position of the lower incisors in treatment. Ricketts (1960 a) found that in 1000 treated orthodontic cases, the average location of the mandibular incisors was 0.5 mm ahead of the A-Pog line at an angle of 21 degrees. He stated that the A-Pog line represents a reciprocal relationship of the denture bases to which the anterior teeth must be related functionally.

Schudy (1963) examined occlusal-mandibular angle (OM angle) in 400 random
malocclusions and related this to the lower incisor to A-Pog line angle. He found that in low OM angle cases the lower incisors were positioned, on average, 1.3 mm ahead of A-Pog line, while in cases of high OM angle cases the average was 3.1 mm ahead of A-Pog line.

Williams (1969) thought that the lower incisor inclination was irrelevant to the facial aesthetics and suggested that its linear relationship to the A-Pog line is critical to lip balance and denture stability. He called the A-Pog line a "diagnostic line" and emphasized the importance of having the incisal edge of the mandibular incisor at or near his diagnostic line for optimal aesthetic results in treatment.

Ricketts (1981) found that in untreated individuals the mean position of the lower incisor with respect to A-Pog line changed very little with growth. The relative position of A point was, however, found to be significantly influenced by treatment, while the position of Pogonion relative to A point was also found to be dependent on growth changes. Therefore the projected incisor to A-Pog line relationship can be affected by the movements of the lower incisors or the A-Pog line or both, and these must be taken into consideration when estimating the direction and degree of the lower incisor movement required.

Linder-Aronson and Corelius (1976), from their study of the relationship between the inclination of the lower incisors and different cephalometric reference lines, indicated that if point A was omitted from consideration in positioning the lower incisors an important functional factor could be ignored. The relative position of the maxilla which carries the upper incisors will affect the proper function of the lower incisors.

Schulhof (1977) also concluded that the position of the maxilla should be considered when placing the lower incisors.
He advocated the use of A-Pog line which is thought to adequately serve as a
guide to this purpose, whereas other reference planes such as Frankfort plane,
facial plane or mandibular plane do not.
Mills (1968) proposed the use of SNI (I= tip of lower incisor crown) based on his
study on the stability of treated lower incisors (1966, 1967) which showed that
the lower incisors tended to return to their original position. Thus, the position of
the lower incisors before treatment was also the treatment objective except in
certain situations where the cause of the lower incisor malposition can be
identified and eliminated.
Hasund (1970) advocated the use of NB line in positioning the lower incisors. His
later analysis (1980) of lower incisor position was essentially an evolution of
Steiner's analysis which introduced the "floating norm" concept by modifying
`ideal' incisor position to take account of the skeletal antero-posterior
discrepancy and chin prominence as guiding variables. Compared with the
Steiner's model, Hasund's method represents a more elaborate and statistical
attempt at individualizing the `ideal' lower incisor position.
Hasund and Boe (1980) and Janson and Hasund (1981) analysed Norwegian and
German samples of adults with Cl I occlusion and harmonious profiles with a view
to refining the floating norm concept to cover a variety of facial types.
As compared with the static nature of lower incisor positioning considered so far,
more recently, there has been a renewed interest in the functional aspects of the
incisor positioning as it relates to various cephalometric reference planes.
Kubein-Meesenberg et al (1986) said that the analysis of incisor position that uses
structures outside the masticatory system cannot provide information for the
treatment of individual cases. They suggested that forces affecting incisor
position that occur within individual stomatognathic systems must be analysed instead, and one has to consider the coordination of incisor position with the dynamics of mandibular movements.

It was suggested that the `ideal' inclination of long axes of lower incisors to the mandibular bases is achieved when their axes are perpendicular to the line connecting the hinge axis and the incisal edge.

Stuart (1972) pointed out that the best position for lower anterior teeth to resist the mechanical forces distributed to them would be at right angles to a radial from the opening and closing axis. In other words, the long axis of the lower incisor is to be at 90 degrees to a line tangent to its incisal edge and intersecting the hinge axis of the mandible. Mechanically speaking, many work implements share the same mechanical advantage.

Stuart's hypothesis was tested by Karr (1976) who found in a sample of 33 `ideal' occlusions, a mean lower incisor inclination of 90.33 degrees to a line touching its incisal edge and intersecting the hinge axis. The study also showed that this 90 degree inclination was more consistent an indicator of these ideal occlusions than was FMA, FMIA, or the interincisal angle, and that Tweed's FMIA standards did not consistently apply to this sample. (McHorris, 1979)

Arehart (1978) did a follow-up study to determine the relationship of the condylar incisal angle (Cl angle) to lower incisor stability. His results were consistent with those of Karr. He found that the changes in the means of differences and corresponding probabilities indicated that the greatest movement towards the normal value occurred in the Cl angle. (McHorris, 1979)
6.1.2. CLINICAL SIGNIFICANCE OF CEPHALOMETRIC PRESCRIPTIONS OF MANDIBULAR INCISORS

Although the topic of cephalometric lower incisor positioning has been subjected to repeated investigations for well over 45 years, conflicting conclusions about their clinical effectiveness have often been drawn in the past, so that the clinician still has inadequate scientific evidence to base his judgement as to the correct labio-lingual position and inclination of the lower incisors. This is further complicated by the nature of orthodontic treatment requirements which might compete with each other in such a way that the requirement of stability might require a compromise in the profile needs of the patient or vice versa. In other words, there is no single ideal position of teeth but a range of "acceptable compromises" which may be subjected to various undesirable influences.

Much of the early literature concludes that it is not desirable to alter the labio-lingual position of the lower incisors. (Margolis, 1943; Cole, 1948; Litowitz, 1948; Weinstein et al, 1963; Mills, 1966)

Among these, Mills' investigation (1966, 1967) is conspicuous in being based on treated cases rather than on a collection of mean values for "ideal" untreated samples. His conclusion that the lower incisor position is largely immutable is also supported by Hixon (1972) who believed that the only value of cephalometric analysis of lower incisors is in ensuring that their pretreatment position is maintained during treatment. This was further supported by Riedel (1976) who pointed out that orthodontic lingual movements of lower incisors that corresponds with normal changes as a result of facial growth changes should remain stable.

On the other hand, so much of modern orthodontic treatment is undertaken without great regard to this principle and in so many cases it appears to be
successful.
Schulhof (1977), based on the results achieved by Ricketts, rejected the theory that the initial labio-lingual position of the lower incisor should be maintained, although he stressed that careful assessments of the soft tissue is essential and that indiscriminate incisor movements should be avoided.
From the available literature, it is not very difficult to see that there have been numerous attempts to discover the 'ideal' cephalometric landmarks and rules to position the lower incisors, and the number of previous attempts without success is an indication of the difficulty of positioning the teeth without any post-treatment problems.
This difficulty stems mainly from the fact that there are numerous unquantifiable factors (both recognized and unrecognized) affecting the position and inclination of the lower incisors, which make it almost impossible to make any reliable predictions regarding the stability of the newly achieved tooth positions.
In addition, the primary objective of the suggested cephalometric prescriptions has always been the aesthetics rather than stability, although it was hoped that stability would follow if the profile requirements were met. (Houston, 1990)
Thus, the 'ideal' relationship of lower incisors to various reference planes was based on studies of patients with a pleasing facial profile. (Steiner, 1953; Tweed, 1954; Downs, 1956; Ricketts, 1957)
The use of cephalometric norms and standards in orthodontics has, therefore, been under many criticisms.
According to Salzmann (1948) diagnosis of malocclusion is not to be based on subjective arbitrarily established criteria or 'standards', but take into consideration of the genetic endowment, ontogenetic growth, and postural
development of the individual patient.

Solow (1980) said that "averages and norms for cephalometric dimensions should not be blindly applied in individual cases."

The use of cephalometric prescriptions, however, should not be too strongly criticized, because it can be used as a yardstick for measuring the severity of existing anomalies.
6.2. CEPHALOMETRIC PLANES OF REFERENCE AND ASSESSMENT OF MANDIBULAR INCISOR POSITION

The cephalometric planes of reference that are currently used for assessment of lower incisors and the ones reported in the literature can be classified as follows.

<table>
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<tr>
<th>REFERENCE LINES</th>
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<td>Extra-mandibular</td>
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<td>APog</td>
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**Fig. 9. Cephalometric reference lines.** (For definitions of planes see p122)

The extra-mandibular planes are the ones using extra-mandibular cephalometric landmarks with or without intra-mandibular landmarks to relate the lower incisors. These include horizontal planes such as Frankfort plane and SN plane, and vertical planes such as A-Pog, NB and N-Pog lines.

The intra-mandibular planes are the ones using the mandibular landmarks only. These include mandibular plane, occlusal plane (functional, mandibular), and condylar-incisal (CI) line, etc.

The intra-mandibular planes are further divided into two groups; skeletal planes (Mpl, CGn) based on skeletal landmarks only, and dental planes (Oocl pl(f,m), CI) based on dental landmarks only or on both skeletal and dental landmarks.
Fig. 10. Intra-mandibular reference planes. (For definitions of points and planes see p119-123)
Fig. 11. Extra-mandibular reference planes. (For definitions of points and planes see p119-123)
For the extra-mandibular reference planes the actual measurement of the inclination of the lower incisors is influenced by three variables.

1. The actual incisor inclination.

2. The mandibular dimensions affecting the position of the intra-mandibular landmarks.

3. The extra-mandibular dimensions affecting the position of the extra-mandibular landmarks.

The use of extra-mandibular planes outside the masticatory system for assessment of lower incisor position has been under many criticisms. This has been partly because of the inherent variability of the position of the reference planes themselves, and partly because of their lack of functional relevance to the lower incisor position.

Bjork (1955) and others have shown that Sella and Nasion can undergo considerable movement with growth independent of other cranial structures. Williams (1969) also recognized the problem of relating lower incisors to distant landmarks such as SN, FH planes and suggested that the cephalometric norms for lower incisor inclination and soft tissue balance were not adequate because most were based on dento-cranial relations rather than dento-facial relations.

Maj (1957) stated that numerous methods of cephalometric analysis are based on arbitrary reference planes which are variable in position and have no functional relation to the masticatory apparatus.

Kubein-Meessenberg et al (1986) also stated that a statistical analysis of incisor position that uses structures outside the masticatory system cannot provide information for the treatment of individual cases.
The horizontal plane landmarks such as Sella (S) and Nasion (N), or Porion (P) and Orbitale (O), for example, have no direct functional relation to the lower incisor positions, although they might be useful points of reference to relate dento-facial structures to "normal head posture".

The profile plane landmarks such as N and A, on the other hand, might be important landmarks from the perspective of establishing balanced facial profile and lower facial harmony, but these still don't relate the incisors 'ideally' to the respective skeletal base. A number of clinicians advocating the use of profile planes assumed that an ideal situation with regards to function and stability would follow automatically once the facial harmony is established. (Williams, 1969)

For the intra-mandibular reference planes, however, there are only two variables without the third non-dental variable outside the mandibular functional unit. The elimination of the third extra-mandibular dimensional variation, thus might make the intra-mandibular reference planes more reliable in assessing the position and inclination of the lower incisors in relation to the apical base of the lower arch.

However, there is also inherent and fairly significant variability of the currently used intra-mandibular landmarks which may or may not be directly related to the lower incisor function, and the assessment of incisor position in the apical base of the arch is again under the influence of this reference plane variation. The reference plane variation is probably the result of combined effects of skeletal morphological variation of the mandible (e.g. mandibular plane) and the operating dento-alveolar compensation mechanism (e.g. oclusal plane, Cl line), resulting in changes in positions of teeth in relation to the skeletal base or maintaining their positions within the overall skeletal framework. Thus the position and inclination
of the occlusal plane are variable in relation to the mandibular plane and the vertical position of the lower incisor in relation to the symphysis. This variability doesn't appear to make the intra-mandibular reference planes much more reliable than the extra-mandibular counterparts.

The difference between these two main groups of reference planes, however, is that with extra-mandibular planes (especially the profile planes), the lower incisors are related to the overall face or both jaws of the stomatognathic system to ensure overall facial harmony, whereas with the intra-mandibular reference planes the lower incisors are related directly or indirectly to the supporting mandibular base to ensure 'ideal' dento-basal relationships.

Although the 'ideal' positioning of the lower incisors has been understood previously in terms of producing a balance or harmony of the overall facial structures through the process of dental compensation and camouflage of the existing skeletal discrepancy, with recent development of the orthognathic surgical procedures the concept of 'ideal' positioning of the lower incisors has changed. Before the introduction and recently renewed acceptance of the surgical procedures, the position of the maxilla was considered important in positioning the lower incisors. (Linder-Aronson, 1976; Schulhof, 1977) Thus the operation of the dento-alveolar compensatory mechanism has been incorporated on a more or less intuitive basis in a number of cephalometric analysis systems. (Steiner, 1953; Ricketts, 1960 a; Hasund and Boe, 1980; Holdaway, 1983)

Steiner (1959) in his analysis introduced a detailed description of dento-basal arrangements corresponding to different values of the sagittal jaw relationship to be used for the setting up of treatment objectives.

A further step towards the automatic incorporation of dento-alveolar
compensatory mechanism into the cephalometric analysis was taken up by Ricketts (1957), who in his visual treatment plan, related incisal position to the A-Pog line. Since this line changes with the changes in jaw relationship it could also be termed "a line of compensation". By relating the incisal edge to this line a certain amount of dento-alveolar compensation is automatically introduced.

With the recent acceptance of the surgical procedures, because of the possibility of the movement of the jaw bases, the concept of "ideal" positioning of the lower incisors has changed from compensated positions to decompensated positions where the teeth are related to their apical bases rather than skeletal base relationships.

When this decompensation concept is applied, the emphasis of the analysis shifts. The jaw relationships are first assessed, followed by assessment of the amount of dento-alveolar compensation that has taken place. The treatment decision then will depend upon whether tooth movements, growth modifications or surgical movements of the jaws are to be used.

The use of intra-mandibular reference planes are more meaningful where the lower incisors are required to be positioned "ideally" in the apical base as in surgical cases. (Ellis and McNamara, 1986)

6.2.1 INTRA-MANDIBULAR REFERENCE PLANES

6.2.1.1. L1 / Mpl or IMPA

There are three variations of the mandibular plane.

1. A line joining gonion to gnathion. (Renfroe, 1948; Steiner, 1953)

2. A line tangent to the lowest point on the profile outline of the symphysis and the inferior border of the ramus. (Downs, 1948, 1952; Johnson, 1950;
Higley, 1954; Schudy 1963; Tweed, 1944, 1954)

3. A line tangent to the most inferior points on the lower border of the mandible. (Noyes et al, 1943; Margolis, 1943; Bjork and Palling, 1954)

This angle is an excellent indicator of mandibular incisor position that is unrelated to the position of the mandible. This is a distinct advantage in cases which vary considerably in the vertical dimension, since the angulation of the mandible is affected in these cases.

It is a useful measurement in surgical cases because it relates the mandibular incisor directly to the bony mandible without extra-mandibular landmarks. (Ellis and McNamara, 1986)

6.2.1.2. L1 / Occl. pl. (Functional Occl. pl. or Lower Incisor Occl. pl.)

This angle relates the lower incisors to the posterior teeth. It is not affected by the relative position of the mandible to the maxilla and cranial base. Because the occlusal plane is involved in actual masticatory function it can be considered as a functional plane as compared with the mandibular plane which is more of a morphological plane.

Schudy (1963) noted that the cant of the occlusal plane is closely related to function and significantly related to treatment. It is the line along which teeth function and the line with which functional balance must be established.

There are three variations of the occlusal plane. (Thayer, 1990)

1. Bisected occlusal plane where a line is drawn bisecting the overlap of the distobuccal cusps of first permanent molars and incisors.

2. Functional occlusal plane where a line is drawn along the molars and
3. Lower incisor occlusal plane where a line is drawn bisecting the overlap of the distobuccal cusps of first permanent molars and to the tip of the lower incisor.

Although this reference plane might have a functional significance, there is a problem of identification and relating the appropriate plane, especially where there are vertical discrepancies in tooth positions. An averaged occlusal plane may not accurately reflect the position of either the maxillary or mandibular dentition, and reproducibility is especially difficult in patients who have excessive curves of Spee. (Ellis and McNamara, 1986)

6.2.1.3. L1 / CI line

This angle relates the lower incisors to the radial from the constructed mandibular hinge axis to the incisal edge. The CI line is also not affected by the position of mandible relative to the maxilla or the cranial base.

Since the two points forming the line are the focal points of mandibular function making contacts with the extra-mandibular structures, there might be a functional and biological significance. Again it can be considered as a functional plane.

This line was originally suggested by Stuart (1964) who stated that the best inclination of the lower incisors to resist the mechanical forces distributed to them is at right angles to a radial from the opening and closing axis.

This was supported by McHorris (1979) who recognized the importance of the condylar positions in harmony with the teeth. He stated that, when the teeth are subservient to the condyles in static as well as moving relations, a more harmonious occlusion would exist.
Kubein-Meesenberg et al (1986) also looked into the mechanical aspects of the mandibular function in the lower incisor region. They concluded that the lower incisors should touch the tangent of the palatal curvature of the upper incisors perpendicularly at the "base point" which is the point where there is a transition from concavity to convexity.

According to Kubein-Meesenberg et al the ideal inclination of the long axes of lower incisors to the mandibular base is achieved when their axes are perpendicular to the line connecting the hinge axis and the incisal edge. The ideal inclination of the upper incisors are achieved when the extension of the tangent to base point curvature passes through the hinge axis.

This reference line has landmarks that are easily identifiable and reproducible unlike occlusal plane which has a functional significance but is not practical to use in many situations.

6.2.1.4. L1 / B-Perp line

This is a linear measurement between the facial aspect of the mandibular incisor and a perpendicular line erected from point B to the mandibular plane. (Ellis and McNamara, 1986)

It is similar to L1 / Mdpl but it also relates the teeth to the alveolar bone. According to Ellis and McNamara, in a balanced face with ideal occlusion this measure should be -1.7 mm (S.D. = 1.97 mm) indicating that the facial aspect of the incisor is 1.7 mm behind the constructed line.

Because of the nature of the curved labial outline of the symphysis and the relative direction of the constructed perpendicular line, the location of the B point
might be difficult in using this reference plane.

6.2.2. EXTRA-MANDIBULAR REFERENCE PLANES

6.2.2.1. L1 / A-Pog line

Although Downs (1948, 1952, 1956) was the first to relate the lower incisors to this line, he gave little diagnostic significance to this measurement. In contrast, Ricketts (1960 a) and Williams (1969) both proposed this measurement of lower incisor position to be of particular value in diagnosis and treatment planning. This is a measure in which both points determining the reference line are located on skeletal structures which may be in abnormal positions and often involved in malocclusions. Maxillary protrusion may cause retrusive L1 / A-Pog measures for a normally positioned lower incisor, and mandibular protrusion will cause more protrusive L1 / A-Pog values. (Ellis and McNamara, 1986)

As it is true for most of the extra-mandibular reference planes, this measure is only appropriate for assessing the profile position of the lower incisors and not the relationship of incisors to the mandibular symphysis. Since the A-Pog line is intended to directly represent the anteriormost extensions of the maxilla and mandible, this line allows the most effective dental compensation for skeletal base discrepancy.

Ricketts (1957), based on his studies of stable cases and consideration of aesthetic lip relationships, advocated positioning the lower incisor at 22 degrees and at +1 mm (i.e. slightly ahead) to the A-Pog line as a clinical objective. The acceptable range was given as +/-2.5 mm.
6.2.2.2. L1 / NB line

Steiner (1953, 1959) was the first to relate the lower incisors to this plane. The position of the lower incisors is measured angularly and linearly with mean angular measurement of 25 degrees and mean linear measurement of +4 mm (i.e. in front of NB line). The angular measure gives the axial procumbency, and the linear measure the relative protrusiveness measured from the facial surface of the incisors to the NB line.

As with A-Pog line, this line also incorporates the factor of mandibular positional variations, thus allowing dental compensation for the skeletal discrepancy. Due to the increased distance between the two determining points of the line, the degree of dental compensation incorporated into the analysis is less than that of A-Pog line which is much shorter than N-B distance.

Again this measure, due to the nature of its landmark positions (i.e. extra-mandibular), is only appropriate for assessing the profile position of the lower incisors and not the relationship of incisors to the mandibular symphysis.

In positioning the lower incisors, Steiner (1959) individualized the lower incisor position according to the patient's projected dental base discrepancy as measured by ANB angle, and the relative prominence of the bony chin as measured by NB-Pog distance. (Holdaway, 1956)

NB-Pog measure is derived from the Holdaway ratio which requires it to equal NB-L1 distance. Steiner (1959) also calculated a range of values for incisor position with varying ANB angles and called it "acceptable compromises".

However, Servoss (1973) commented that the Steiner's acceptable compromises were derived from a geometric procedure involving the manipulation of various angles whilst maintaining the angle of the upper incisors to the NB line, and
questioned the biological validity of such a geometric model.
Steiner used the following diagram to summarize the diagnostic factors in positioning incisors.

![Diagram](image)

**Fig. 12. Steiner's diagram describing incisor relationships.**

### 6.2.2.3. L1 / Frankfort plane (FMIA)

The Frankfort-mandibular incisor angle as proposed by Tweed (1954) has been a popular indicator of mandibular incisor position in combination with IMPA and FMIA. These three angles form the 'Tweed triangle' which was presented as a diagnostic aid to position lower incisors for optimal facial aesthetics.

According to the Tweed philosophy, with an average FMA, the IMPA is altered to maintain the FMIA of 65 degrees. Later Tweed (1966) included vertical skeletal
discrepancy into consideration and FMIA for FMA of 30 degrees upwards was maintained at 65 degrees, while FMIA for FMA of 20 degrees was increased to 72 degrees to a maximum of 80 degrees. According to Tweed, in approximately 25% of cases where mandibular growth was considered unfavourable, the attainment of FMIA goal of 65 degrees was impossible, and such cases were thus considered to be of poor prognosis.

The L1/FH measurement (FMIA) involves only the angular orientation of the lower incisors to the reference plane, and thus the Frankfort plane is inappropriate for the assessment of the antero-posterior position of the incisors. (Williams, 1985) Furthermore, this angle is strongly influenced by the vertical dimension and orientation of the mandible in relation to the Frankfort plane, and thus it has little utility in cases which require surgical movement of the jaws.

As was true with the previous extra-mandibular reference planes, this plane also doesn't relate the lower incisors to the supporting alveolar base and there is no theoretical functional relevance of the plane to the lower incisor position and inclination.

6.3. THE CEPHALOMETRIC NORMS

The cephalometric norms used in assessing position of lower incisors are derived from a wide range of values which may run from a very low to a very high value. The validity of these mean values in clinical diagnosis and treatment planning has been questioned by a number of clinicians.

Brodie (1944) stated that the axial inclination of the lower incisors is an individual characteristic which shows a great range of variability in any sample of normal or abnormal occlusions and to accept its mean value as a norm is wholly unjustifiable.
according to any scientific standards. This criticism was supported by a number of people: Benson (1947), Bushra (1948), Johnson (1950), Downs (1952), Graber (1952, 1956, 1958), Krogman (1958), Salzmann (1964), all generally accepting that the range of variation found (especially with the incisor mandibular plane angle) were too large to be applied to the individual. (Edwards, 1968)

Salzmann (1960) also stated that, although standards drawn from persons with excellent occlusions have been used as a means of deciding treatment objectives, there is no scientific justification for this. He pointed out that morphological deviation from a mean, however large it may be, cannot per se be looked upon as a condition requiring orthodontic correction.

Lundstrom (1954) stated that standards based on norms involve a significant degree of subjectivity on the part of the investigator. In addition, treatment which aims at a mean norm may not result in acceptable improvement in the individual. The aim of orthodontic treatment is to improve the state of occlusion and Lundstrom questions whether this can be achieved by aiming at a mean norm.

According to Gianelly and Goldman (1971, p12) the cephalometric standard is not a biologic norm because it does not represent the facial harmony that exists in the largest number of people. It, however, represents a bias because the `norm' is established by analyzing the cephalograms of a group of individuals who were selected because their cranio-facial configuration was considered "in balance". According to Salzmann (1964), mean values are not to be accepted as absolute criteria in clinical diagnosis. It is not the mean per se that should be used as a criterion but an established normal range about the mean.

Graber (1972) also stated that the normal in physiology is always a range, never a
point. Merrow and Broadbent (1992) also commented that when the obvious differences in age, sex, race and environment are combined with vicissitudes of biologic and genetic variation, it is obvious that the variation is indeed the name of the game.

Variability is the rule in the world of biology. Consequently, comparing individuals with statistically derived 'norms' involves a certain hazard. Watson (1982) thus warned against heavy dependence on the cephalometric norms without careful consideration of factors such as age, sex, race, facial type and skeletal pattern. Graber (1954) cited Simon as best expressing the concept of the use of norm values.
"..... an exact ideal normal does not exist, cannot exist, and this is our enigma. In theory we will never find the normal; in practice, we forever feel its need and apply it constantly."

With the increase in the amount of accumulated data on cephalometric norms according to age, sex, and racial groupings and subgroupings, the clinical application of the norms is expected to be more 'individualized' in future. With the recent introduction of computer technology, the handling of large amount of data required in comparing, organizing, sorting and retrieving information in a clinically useful form has been made possible.

Ricketts et al (1972) noted the advantage of the clinical application of the computerized cephalometrics, and stressed the need for individualizing measurements according to age, sex, ethnic type, and degree of maturation of each patient, so that the applied cephalometric norms would be more biologically 'meaningful' for the individuals receiving treatment.

More recently there has been further attempts to individualize the application of
cephalometric norms according to various guiding variables. Hasund and Boe (1980) introduced a 'floating norm' concept when positioning the lower incisors. The wide variations from the norm in the description of cephalometric variables follow a standard distribution when taken individually, but when taken together they show a strong inter-correlation. The degree of prognathism, the inclination of the mandibular and maxillary planes, and the angle of the cranial base are as a rule closely related. According to the 'floating norm' concept, the specific norm in the area of interest is individualized by guiding variables (in the case of lower incisors ANB, ML-NL, N angle) which are combined in a multiple regression equation.

Despite the fact that the current norms are not in themselves diagnostic, and routine cephalometric measurements are not all as reliable as desired as pointed out by Moyers and Bookstein (1981), Hixon (1956) believed that it still provided a useful frame of reference.

Although many can also dispute the non-biologic aspects of cephalometric norms, Gianelly and Goldman (1971a, p13) commented that orthodontists attempt to create more facial harmony than exists in the biologic norm, and the cephalometric norm is an aid to accomplish this objective.
1. AIM OF THE STUDY

It has been stated that the position of the mandibular incisors is probably the most important key in diagnosis and treatment planning. Where there is a skeletal discrepancy, apart from the space considerations for the alignment of incisors, the orthodontic treatment decision with regard to the lower incisors basically revolves around whether to dentally compensate for the existing skeletal discrepancy or to decompensate for surgical correction of the discrepancy itself.

When the decision between the dental compensation and the decompensation is made, then how much to compensate or to decompensate needs to be decided. In order to help making these decisions, a number of cephalometric methods to determine the position for the lower incisors have been suggested to satisfy some of the basic treatment requirements of facial harmony, stability, function and the health of the supporting gingival and periodontal tissues. However, from a review of the literature their various limitations are clear; most rely heavily on various cephalometric points, lines and planes which are themselves subject to variation and errors in identification, and are in some cases remote from the area of interest.

Although there is some variation in the use of reference planes to position the lower incisors among different clinicians, it is generally believed that in an "ideal" situation, or where dental decompensation is required, the lower incisor apex should be placed in the centre of the alveolar base and the incisor inclination properly related to the reference plane being used.

In other words, the final position of the incisors is basically dictated by the position of the root apices in the apical base and the inclination of the teeth.
Most of the cephalometric analyses available for lower incisor assessment, however, only look at the incisal edge in terms of its antero-posterior position or sometimes in combination with the inclination of the incisors. This has the advantage of practical convenience but ignores the important area of the root apex position within the apical base. In these analyses it is assumed either that the incisor root apex would be positioned "ideally" in the apical base in all situations, or that the lower incisor apex position is not important as long as the crown is positioned in harmony with the rest of the dentition and face.

Practical though it may be, to just consider the crown positions and accept the resulting root apex positions in the apical base, it may not be a desirable sequence of planning final incisor positions. Although there is a relative freedom of movement of the incisor crowns, the movement of the root apices is restricted within the apical base. The projected lower incisor crown position, usually measured from the incisal edge, may therefore be considered as a treatment goal while the apex position and the inclination can be thought of as the limiting factors in achieving this goal. The better sequence of planning would be to determine the possible positions of the incisors in the apical base and their inclinations which would automatically dictate the final crown positions or give a range of "biologically acceptable" incisor crown positions from which the final treatment goal can be determined.

The aim of this study is to cephalometrically examine, in untreated permanent dentitions of adolescent and young adult subjects, the lower incisor root apex positions in the apical base as measured by the ratio of the perpendicular linear distance from the root apex to the lingual symphyseal outline \( x \) and the sum of
the perpendicular distances from the root apex to the lingual and labial symphyseal outlines (x+y), and the lower incisor inclinations.

This is

1. to identify the naturally occurring range of apical positions in the apical base with varying lower incisor inclinations. This would give an indication of the limits of dento-alveolar compensation to skeletal base discrepancy. This natural compensatory pattern recognized can be applied in the actual treatment to minimize straining of the alveolar base which might be a contributing factor in breakdown of the supporting hard and soft tissues, or relapse of teeth.

2. to test for any significant correlation between the apex positions and the inclinations of the incisors. This will demonstrate the pattern of naturally occurring dental compensation (in terms of relationship between the inclination and the apex position) and will allow clinicians to determine the treatment goal which is biologically acceptable rather than geometrically "ideal".
2. MATERIAL

Pretreatment lateral cephalometric radiographs of 90 subjects were selected from the files of cases presented for the final examinations in the MDSc program at the University of Sydney, and the cases that are currently under treatment at the University Orthodontic Clinic. The radiographs were taken within the last three consecutive years in the Radiology Department of the United Dental Hospital of Sydney.

All classes of malocclusions were represented, including Class I, Class II and Class III skeletal types as well as high, normal and low angle vertical facial types. Although it was not considered critical for the study, an attempt was made to evenly distribute the number of cases between the different skeletal types.

Class III low angle cases could not be found and thus additional 10 Class I normal cases were used instead to replace this subgroup.

<table>
<thead>
<tr>
<th></th>
<th>Class I (30) (ANB=3+/−2)</th>
<th>Class II (30) (ANB &gt; 5)</th>
<th>Class III (30) (ANB &lt; 1)</th>
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<td>High (30) (FH-Mpl &gt; 29)</td>
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<td>10</td>
<td>10</td>
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<tr>
<td>Normal (30) (FH-Mpl=24+/−5)</td>
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<td>10</td>
</tr>
<tr>
<td>Low (30) (FH-Mpl &lt; 19)</td>
<td>10</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

Total: 90 cases

The ages ranged from 12 years to 28 years. The mean age of the group was 15.3 years.

The criteria that were employed in the selection of the radiographs for the present study are as follows.
1. Pretreatment lateral cephalogram with no previous history of orthodontic treatment, pathological conditions or identifiable cranio-facial syndromes.

2. Clearly identifiable anatomical landmarks, especially the FH plane landmarks, point A, mandibular symphyseal outline and lower central incisor crown and root outlines, recognising the difficulty of identifying the incisor apices.

3. Cases with pretreatment study models taken at the same time as the lateral cephalogram to help identification of the lower central incisor root positions on the lateral cephalogram by comparing the incisor crown position on the cast and the film.

4. Cases with reasonably well aligned lower central incisors, both positioned in the same antero-posterior plane. Cases with excessive crowding of the lower incisors were discarded.

5. Cases in permanent dentition over 12 years of age.
3. METHOD

3.1. RADIOGRAPHIC EQUIPMENT

The cephalometric radiographs were taken using the cephalometric equipment in the Radiology Department of the United Dental Hospital, Sydney. The radiographs used in this study were taken from one machine, Orthopantomograph 5 made by Siemens of West Germany.

For each exposure the machine was set as follows: There were some variations in the settings depending on the size of the patient to optimize the quality of the radiographs.

1. 15 mA
2. 80-85 kV
3. 0.6, 0.8 sec. exposure time

Target-film distance of 152.5 Cm was used and the film was placed at a constant 15 Cm from the midsagittal plane.

Alignment of the central ray and ear rods was checked first. This was done by taking radiographs of the ear rods and then adjusting the central ray and the position of the ear rod holders till symmetrical superimposition of the ear rod holes resulted.

Fast films and rare-earth intensifying screens were used and the magnification at the mid-sagittal plane of the head was 12 percent.
3.2. TRACING OF RADIOGRAPHS

Each radiograph was traced in a dark room using a personal cephalometric viewer which consisted of a 40 watt fluorescent tube sealed under a 35x 43 Cm opalescent illuminator.

A black masking paper with a central circular aperture of 8 Cm diameter was used to reduce extraneous light from the viewer. This was found to help considerably in definition of anatomical landmarks such as incisor apices, lingual surface of the mandibular symphysis, point N and point A.

For bilateral cephalometric landmarks both right and left sides were traced separately and an average of the two was marked with a broken line. Where there was a great horizontal or vertical discrepancy between the two sides the cephalogram was excluded from the study.

The most difficult landmark to identify in the radiograph and yet the most important landmark to be identified accurately in this study was the lower central incisor apices in the apical base. This was because of the superimposition of the other incisor teeth as well as the canines on both sides.

The technique used to trace the lower central incisor root apices is as follows;

1. The lower incisor positions and relationships were examined on the study models of each case, and from this the crowns of the central incisors were identified in the lateral cephalogram.

2. The lower central incisor crown was traced.

3. From the knowledge of tooth anatomy and the traced incisor crown outline, and by eliminating extraneous light, using a masking paper with an 8 Cm circular aperture, labial root outline of the central incisors was visually delineated to the apex from those of lateral incisors as accurately
as possible.

4. Lower incisor template produced by Ormco-Sybron was superimposed in the traced incisor crown outline and the previously delineated labial root outline was confirmed and traced to the apex.

5. The template was only used as a guide for the labial crown and root outline and the root length, and is used to confirm the visually delineated incisor root outline and the apex. Where it was difficult to clearly delineate the central incisor roots, the template was used to trace the labial outline to the apex.

The template incisor tooth length was calculated from the known average lower central incisor tooth length and the magnification of the radiograph at the midsagittal plane.

The average length of the mandibular central incisors is found to be 20.5 mm (Grossman, 1960), 20.7 mm (Brescia, 1961), 21.5 mm (Wheeler, 1965), 21.8 mm (Ingle, Beveridge, Luebke, Walter, Zidell, 1976) with approximately 5.7 mm of range of variation from 19.4 mm to 25.1 mm.

The magnification of the radiograph was calculated from the metal ruler in the radiograph. Because all the radiographs were taken from a single machine with the same target-film distance and film-midsagittal plane distance the magnification was calculated to approximately 12.2% in all cases.

Template incisor length = (20.5+ 20.7+ 21.5+ 21.8) x 1.122 /4

= 23.7

Using a template and a clutch pencil with a sharpened 0.5 mm 2H Steadler Mars Micrograph lead, 20 incisors were drawn and the tooth lengths were measured. The average tooth length produced was 23.5 mm with a standard deviation of 0.5
The tracings were done on 'Unitek/3M' acetate tracing papers using the same clutch pencil with a 0.5 mm Steadtler Mars Micrograph 2H lead. All of the tracings were done by one investigator.

Eight radiographs were randomly selected from each subgroup. These were then traced and digitized on two separate occasions, separated by at least one week interval, for statistical analysis of reproducibility. The 90 sample radiographs were then traced and digitized and the measurement variables were correlated for statistical significance.
3.3. LANDMARKS AND MEASUREMENTS

The points and planes of reference used in this study are defined as follows;

3.3.1. POINTS

Anatomic Porion (P)

The outer upper margin of the averaged right and left external auditory canal outlines.

Orbitale (O)

The lowest point on the averaged right and left orbital margin outlines.

Nasion (N)

The point where the midsagittal plane intersects the most anterior point of the nasofrontal suture.

Subspinale (A)

The innermost point on the curved outline of the maxillary labial bony profile between ANS and alveolar crest.

Supramentale (B)

The innermost point on the curved outline between chin and alveolar crest.

Incisor inferius (ii)

The tip of the crown of the mandibular central incisor.

Incisor apex (ia)

The apex of the mandibular central incisor root.

Menton (Me)

The lowest point on the profile outline of the mandibular symphysis. The point of contact with the line drawn tangent to the mandibular symphysis and the lower border of ramus.
Pogonion (Pog)
The most anterior point on the profile outline of the mandibular symphysis.
The point of contact with the line drawn from N, tangent to the mandibular symphysis.

Gnathion (Gn)
The point on the profile outline of the mandibular symphysis approximately half-way between Pogonion and Menton.

Point C (C)
The mid-point of the averaged right and left condylar processes on the inferior outline of the occipital bone. This is a modification of Rickett’s D.C. point.

Symphyseal concavity point (sc)
The point on the labial profile outline of mandibular symphysis furthest from the dento-symphyseal line (S line). For definition of S line see p 156.

Labial symphysis point (LaSy)
The point on the labial profile outline of mandibular symphysis closest to la.

Lingual symphysis point (LiSy)
The point on the lingual profile outline of mandibular symphysis closest to la.

Lower permanent first premolar cusp tip (LPC)
Averaged right and left permanent mandibular 1st premolar cusp tip.

Lower permanent first molar cusp tip (LMC)
The highest cusp tip of the averaged right and left mandibular first molars.
Fig. 13. Cephalometric landmarks. (For definitions see p119-120)
3.3.2. PLANES

Frankfurt Plane (FH)
A cephalometric line connecting P and O.

NA Plane (NA)
A line joining N and A.

NB Plane (NB)
A line joining N and B.

APog Plane (APog)
A line joining A and Pog.

Mandibular Plane (Mpl)
A line tangential to the lower symphyseal outline and the lower posterior end of the mandibular body outline averaged between right and left mandibular images.

C-Gn Plane (CGn)
A line joining C and Gn.

Functional occlusal plane (Occl Plf)
A line tangential to the cusps of the averaged right and left mandibular first permanent molars and the first permanent premolars.

Mandibular occlusal plane (Occl Plm)
A line tangential to the cusps of the averaged right and left mandibular first permanent molars and the mandibular incisal tip.

CI Plane (Cl)
A line joining C and li.

Dentosymphyseal Line (S line)
A line tangential to li and the profile outline of the mandibular symphysis.
Mandibular Incisor Axis (l)

A line representing the long axis of the mandibular central incisor tooth
joining the incisal edge (li) and the root apex (la).

3.3.3. MEASUREMENTS

Measurements for classification

ANB
FH-Mpl

Angular measure of lower incisor inclination in relation to the extramandibular planes

I-FH
I-NB
I-APog

Angular measure of lower incisor inclination in relation to the intramandibular planes

Skeletal Planes
I-Mpl
I-CGn

Dental Planes
I-Occl Pl_f
I-Occl Pl_m
I-Cl

Angular measure of dento-alveolar curvature in relation to the mandibular symphysis

li-sc-la
Measure of lower incisor root apex position in the apical base

\[
x / (x+y)
\]

- \(x\): The shortest distance from the la to the lingual cortical plate (mm).
- \(y\): The shortest distance from the la to the labial cortical plate (mm).
4. SOURCES OF ERROR

There are three main sources of error in measurements from cephalometric radiographs. (Baumrind and Frantz, 1971b)

4.1. Errors of projection.

4.2. Errors of landmark identification.

4.3. Errors of measurement.

4.1. Errors of projection

Although these errors may be of significance they are usually considered to be of less importance than other errors. (Hatton and Grainger, 1958; Miller et al, 1966; Savara et al, 1966; Carlsson, 1967; Baumrind and Franz, 1971a; Mitgard et al, 1974; Houston et al, 1986)

Errors of projection arise because of the fact that the head film is a two dimensional picture of a three dimensional object.

Since the rays which produce the shadow are nonparallel and originate from a very small source, head films are always distorted enlargements, the enlargement factor varying with the plane at which the estimated point lies. Head films are further distorted by foreshortening of distances between points lying in different planes and by radial displacement of all points and structures not on the principal axis. (Baumrind and Franz, 1971a)

In addition, there is also the possibility of malalignment of the different components of the cephalographic equipment, including the variation of the head position in a cephalostat when radiographs are being taken. (Ahlqvist et al, 1986)

Baumrind and Frantz (1971 a) stated that precise positioning in any head holder is very difficult, resulting in a situation in which the true anatomic midsagittal plane
only rarely coincides with the nominal midsagittal plane of the X-ray-cephalostat system. They thought that this source of error has asymmetric effects in the sense that it always makes the angle between objects in the true midsagittal plane appear more obtuse than it really is. However, this is only true when the lines forming the angle diverge away in the opposite direction from the line perpendicular to the true vertical. If the lines are on the same side of the perpendicular line then with head rotation the angular measurement will decrease. The actual error involved would equal the actual angle without head rotation multiplied by the degree of rotation per 90 degrees. Therefore, the overall effect of head rotation would vary depending on the size of the angle being measured and the position of the lines forming the angle in relation to the perpendicular line to the true vertical.

Alqvist et al (1986) looked at different possibilities for projection errors and stated that the relations between the different components of the cephalographic system can be affected in a number of ways.

a. The focal spot, the cephalostat, and the film may be linearly displaced in relation to each other.

b. The cephalostat and the film may be rotated with respect to each other.

c. The patient may be linearly displaced and/or rotated in relation to the cephalographic system.

It was thought that the malalignment of the equipment components was of minor importance as compared to the malposition of the patient's head in the cephalostat provided that the equipment was properly adjusted. Alqvist et al (1983, 1986) theoretically calculated the magnitude of the projection error on length measurements and concluded that projection errors in linear
measurements were not a serious problem in cephalometry. They found that the rotation of the patient's head up to 5 degrees from the ideal position usually results in errors that are less than one percent. Such error is thought to be insignificant and in most instances concealed by other errors. Rotation or tilting of head by more than 5 degrees is discernible and should not arise in skilful clinical work.

In the clinical studies of Solow (1966) and Mittgard et al (1974), duplicate radiographs were available and the errors between tracings from separate radiographs were calculated. These errors did not differ greatly from those arising when two tracings were obtained from a single radiograph. It had been assumed from these findings that the random errors introduced in obtaining cephalometric radiographs are negligible.

Houston et al (1986) evaluated the errors introduced at the various stages of obtaining cephalometric measurements and concluded that the errors in obtaining radiographs can be very small provided that due care is given to positioning the patient in the cephalostat.

The cephalometric radiographs used in this study were taken in a standard manner according to the protocol in the Radiology Department and every effort was made to minimize errors from head positioning in the cephalostat.

4.2. Errors of landmark identification

These are one of the most important sources of error in cephalometry and arise because of the uncertainty in the visual identification of radiographic landmarks. Mittgard et al (1974) concluded from their study that inaccuracy of measurement
of head films is for most part, dependent on the uncertainty of landmark identification.
The lack of resolution of the radiographic image prevents accurate landmark identification, and according to Cohen (1984) this can occur either through unsharpness of the image or lack of contrast.

a. Sharpness

Sharpness can be defined as the rate of change of image density across the boundary between a point of interest and the surrounding area.
Radiographic image sharpness depends on a number of factors.
1. Geometric, photographic sharpness of the subject itself.
2. Movement of the subject during exposure.
3. Grain size of the film; In practical terms the grain size is so small as to become unimportant when compared with other causes of unsharpness.
4. Intensifying screens used to reduce the X-ray exposure produce a loss of sharpness.

b. Contrast

Contrast can be defined as the difference in density between adjacent areas. Contrast is affected by following factors;
1. Superimposition of landmarks in different planes.
   e.g. apices of lower incisors.
2. Position of landmarks in relation to other bony structures.
3. The image recording system. The kV is important because high kV values level out differences in relative X-ray absorption and reduce the contrast. The presence of scatter radiation also reduces contrast.
4. The conditions of viewing.
In addition to these, Baumrind and Frantz (1971 a) noted the difficulty of identifying landmarks that are placed on curves with wide radii. In their study on the landmark identification they found that the magnitude of error varies greatly from landmark to landmark and the distribution of errors for most landmarks is not random but rather systematic.

They also looked at the impact of these landmark identification errors on angular and linear measurements, and listed three factors that influence the extent to which these errors affect the actual measurements. These are;

1. The actual magnitude of error involved in identifying the specific landmarks.
2. Separation distance among the landmarks.
3. The direction from which the line segment connecting the landmarks intercept the envelop of errors.

The key area of interest in this study is the lower incisor region, but according to several observers (Hixon, 1956; Backlund, 1963; Mills, 1964, 1966; Bennet and Smales, 1969; Kvam and Krogstad, 1969; Baumrind and Franz, 1971a) the level of reliability of tracings of incisor teeth is particularly low. Hixon (1956) and Broadway et al (1962) found that the inter-tracer error is generally higher than intra-tracer error and according to Kvam and Krogstad (1969) the level of error is affected by experience and training.

In order to minimize the tracing errors in this study, as was advocated by Baumrind and Frantz (1971 b) head films were interpreted under standardized and optimal conditions. A number of radiographs were traced several times as a trial run to improve the consistency of tracing. Then eight radiographs were randomly selected from each sub-group of the study sample and traced by one investigator
and checked by another to verify accuracy. These were then traced on two
different occasions, separated by at least one week interval for statistical
analysis of reproducibility.
The procedure used to trace the lower incisor roots is described previously.

Cephalometric landmarks and planes were clearly defined and located strictly
according to the definition, especially those on a curved outline with wide radii.

4.3. Errors of measurement
These involve mechanical errors in drawing lines between points and measuring
linear or angular measurements with a ruler or a protractor.
Although conceptually trivial, these errors of measurement are very real.
Baumrind and Frantz (1971 b) thought that with the development of electronic
plotting equipment mechanical errors of this type could be entirely eliminated.
With the electronic plotting device (digitizer) the film to be measured is placed on a
tracing table and a cursor is positioned by eye over each of the landmarks in turn.
At each stage a recording is made denoting the position of the cursor in two
dimensions.
Richardson (1981) made a comparative study of reproducibility of the use of
digitizer when compared with conventional tracing and measurements. He found
that the digitizer showed only a small advantage over tracing techniques. It was
noted that much of the measuring accuracy of the digitizer is wasted due to the
poorly defined points whose location is often subjective.
Cohen (1984) compared the reproducibility of different methods of use of the
digitizer in the analysis of cephalometric radiographs in terms of their co-ordinate
error and cephalometric angular measurement error. Although it was thought that tracing prior to use of the digitizer would make location of the points more reliable, it was found that direct registration of points from untraced films with the digitizer was more reliable.

The possible explanation provided was that, in measuring a tracing, two judgements have to be made- firstly in drawing the tracing and secondly in attempting to record the exact position of a pencil line.

When attempting to take measurements (angular) directly from the film, however, the error was larger due to the difficulty in landmark identification. Since many of the landmarks involved construction lines in their identification, there was difficulty in locating these landmarks without initial tracing with clearly identified points. However, Cohen found that the errors were comparable, whether the plotting was made on the film directly, or whether some form of tracing was used.

In this study the cephalometric films are traced as required for the necessary landmarks, and points and lines are clearly marked and constructed. Then this tracing is digitized with a Scriptel high resolution digitizer on-line to a minicomputer.
5. RESULTS and DISCUSSION

5.1. Operator error test

In order to determine the error involved in actual tracing and measurement process two reproducibility tests were carried out.

1. The first was to determine the reliability of the overall measurement process including tracing as well as digitization. Eight radiographs were selected randomly, each representing one of the eight subgroups. Each of the radiographs was traced on two different occasions, separated by at least one week, and then digitized.

2. The second was to determine the accuracy of the digitization process itself. The tracings of the eight selected radiographs were digitized twice, separated by one week interval.

The mean and standard deviation were calculated for each variable, from the original sample of 90 cases. In addition, standard deviations were calculated for the differences between the first and second (retraced and redigitized) measurements taken from the 8 selected cases for the measurement error test. The variance of the method error for the individual measurement was calculated according to the formula

\[ \text{Var. (S.D.}^2) = \frac{d^2}{2N} \]

where \(d\) is the difference between the two measurements and \(N\) is the number of cases used in the error test. The method error was expressed as a percentage of the total variance of the sample (S.D.\(^2\)(90)) for each variable.
<table>
<thead>
<tr>
<th>MEASUREMENT</th>
<th>N</th>
<th>S.D.(8) of diff.</th>
<th>Var(8) of diff.</th>
<th>Mean(90)</th>
<th>S.D.²(90)</th>
<th>Var(8) of diff. in % of S.D.²(90)</th>
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<tr>
<td>ANB</td>
<td>8</td>
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<td>0.88</td>
</tr>
<tr>
<td>L1-Mpl</td>
<td>8</td>
<td>0.66</td>
<td>0.47</td>
<td>94.66</td>
<td>110.19</td>
<td>0.43</td>
</tr>
<tr>
<td>L1-CGn</td>
<td>8</td>
<td>0.61</td>
<td>0.37</td>
<td>72.51</td>
<td>81.69</td>
<td>0.45</td>
</tr>
<tr>
<td>L1-Occ(f)</td>
<td>8</td>
<td>0.73</td>
<td>0.54</td>
<td>68.45</td>
<td>90.11</td>
<td>0.60</td>
</tr>
<tr>
<td>L1-Occ(m)</td>
<td>8</td>
<td>0.60</td>
<td>0.36</td>
<td>65.30</td>
<td>81.51</td>
<td>0.44</td>
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<tr>
<td>L1-Cl</td>
<td>8</td>
<td>0.50</td>
<td>0.25</td>
<td>86.75</td>
<td>100.80</td>
<td>0.25</td>
</tr>
<tr>
<td>li-so-Pog</td>
<td>8</td>
<td>0.85</td>
<td>0.72</td>
<td>156.54</td>
<td>65.61</td>
<td>1.10</td>
</tr>
<tr>
<td>x/x+y</td>
<td>8</td>
<td>2.34</td>
<td>5.48</td>
<td>42.45</td>
<td>99.07</td>
<td>5.53</td>
</tr>
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</table>

**TABLE 1. Overall measurement error; tracing and digitizing error.**

<table>
<thead>
<tr>
<th>MEASUREMENT</th>
<th>N</th>
<th>S.D.(8) of diff.</th>
<th>Var(8) of diff.</th>
<th>Mean(90)</th>
<th>S.D.²(90)</th>
<th>Var(8) of diff. in % of S.D.²(90)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANB</td>
<td>8</td>
<td>0.06</td>
<td>0.00</td>
<td>3.02</td>
<td>14.60</td>
<td>0.03</td>
</tr>
<tr>
<td>FH-Mpl</td>
<td>8</td>
<td>0.06</td>
<td>0.00</td>
<td>25.25</td>
<td>51.15</td>
<td>0.01</td>
</tr>
<tr>
<td>L1-FH</td>
<td>8</td>
<td>0.20</td>
<td>0.04</td>
<td>60.09</td>
<td>95.24</td>
<td>0.04</td>
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<tr>
<td>L1-NB</td>
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<td>0.15</td>
<td>0.02</td>
<td>26.26</td>
<td>69.06</td>
<td>0.03</td>
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<tr>
<td>L1-Apog</td>
<td>8</td>
<td>0.16</td>
<td>0.02</td>
<td>25.63</td>
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<td>0.06</td>
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<tr>
<td>L1-Mpl</td>
<td>8</td>
<td>0.22</td>
<td>0.05</td>
<td>94.66</td>
<td>110.19</td>
<td>0.04</td>
</tr>
<tr>
<td>L1-CGn</td>
<td>8</td>
<td>0.17</td>
<td>0.03</td>
<td>72.51</td>
<td>81.69</td>
<td>0.04</td>
</tr>
<tr>
<td>L1-Occ(f)</td>
<td>8</td>
<td>0.22</td>
<td>0.05</td>
<td>68.45</td>
<td>90.11</td>
<td>0.05</td>
</tr>
<tr>
<td>L1-Occ(m)</td>
<td>8</td>
<td>0.15</td>
<td>0.02</td>
<td>65.30</td>
<td>81.51</td>
<td>0.03</td>
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<tr>
<td>L1-Cl</td>
<td>8</td>
<td>0.17</td>
<td>0.03</td>
<td>86.75</td>
<td>100.80</td>
<td>0.03</td>
</tr>
<tr>
<td>li-so-Pog</td>
<td>8</td>
<td>0.27</td>
<td>0.07</td>
<td>156.54</td>
<td>65.61</td>
<td>0.11</td>
</tr>
<tr>
<td>x/x+y</td>
<td>8</td>
<td>0.61</td>
<td>0.38</td>
<td>42.45</td>
<td>99.07</td>
<td>0.38</td>
</tr>
</tbody>
</table>

**TABLE 2. Digitizing error.**

The measurement error range was 0.25%-5.53% of the total variance. (Table 1) It can be seen that there was a large measurement error of 5.53% for the variable, x/x+y. Correlation coefficients based on this variable may therefore be
expected to underestimate the true values.
Apart from this, there was no other variable with significant measurement error.
The error involved in digitization process was not significant for all of the
variables, all being less than 0.5% of the total variance.
The method errors involved in this study were found to be much less than those
reported in earlier investigations. (Solow, 1966; Corelius and Linder-Aronson,
1976; Lundstrom and McWilliam, 1984)
This may be due to our case selection process where radiographs of poor quality
were excluded from the study, and only those with reasonably clear radiographic
landmarks and minimal mandibular incisor crowding were included.
In the case of variables for which the error variance was greater than 3% of the
total variance, there is a risk that in simple correlation analysis the size of the true
correlation with other variables may be underestimated. (Corelius and Linder-
Aronson, 1976)
5.2. Correlation results

Pearson’s product-moment correlation coefficients (r) were computed to determine how the mandibular incisor inclination is related to the ANB, FH-Mpl. and x/x+y measurements.

<table>
<thead>
<tr>
<th></th>
<th>ANB</th>
<th>FH-Mpl</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
<th>C9</th>
<th>C10</th>
<th>C11</th>
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</thead>
<tbody>
<tr>
<td>FH-Mpl</td>
<td>-0.027</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>C3</td>
<td>-0.667</td>
<td>-0.259</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C4</td>
<td>0.542</td>
<td>0.159</td>
<td>-0.933</td>
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<tr>
<td>C5</td>
<td>0.064</td>
<td>0.049</td>
<td>-0.702</td>
<td>0.838</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>C6</td>
<td>0.639</td>
<td>-0.440</td>
<td>-0.753</td>
<td>0.760</td>
<td>0.620</td>
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</tr>
<tr>
<td>C7</td>
<td>0.633</td>
<td>-0.399</td>
<td>-0.873</td>
<td>0.882</td>
<td>0.728</td>
<td>0.947</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>C8</td>
<td>-0.599</td>
<td>0.097</td>
<td>0.853</td>
<td>-0.865</td>
<td>-0.717</td>
<td>-0.859</td>
<td>-0.917</td>
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</tr>
<tr>
<td>C9</td>
<td>-0.713</td>
<td>0.163</td>
<td>0.862</td>
<td>-0.846</td>
<td>-0.637</td>
<td>-0.912</td>
<td>-0.942</td>
<td>0.942</td>
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</tr>
<tr>
<td>C10</td>
<td>-0.712</td>
<td>0.054</td>
<td>0.933</td>
<td>-0.903</td>
<td>-0.687</td>
<td>-0.904</td>
<td>-0.978</td>
<td>0.920</td>
<td>0.958</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C11</td>
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<td>0.135</td>
<td>0.633</td>
<td>-0.588</td>
<td>-0.581</td>
<td>-0.694</td>
<td>-0.697</td>
<td>0.672</td>
<td>0.700</td>
<td>0.688</td>
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</tr>
<tr>
<td>x/x+y</td>
<td>-0.318</td>
<td>0.350</td>
<td>0.401</td>
<td>-0.406</td>
<td>-0.428</td>
<td>-0.612</td>
<td>-0.535</td>
<td>0.447</td>
<td>0.522</td>
<td>0.514</td>
<td>0.528</td>
</tr>
</tbody>
</table>

TABLE 3. Correlational matrix between mandibular incisor inclination measurements, x/x+y, ANB and FH-Mpl.

C3: L1-FH, C4: L1-NB, C5: L1-APog, C6: L1-Mpl, C7: L1-CGn, C8: L1-Occl(f),
C9: L1-Occl(m), C10: L1-CI, C11: II-ac-Pog.

5.2.1. AP skeletal discrepancy (ANB) vs mandibular incisor inclination

With the antero-posterior skeletal discrepancy (ANB), when the incisors are related to the intra-mandibular reference planes (Mpl, CGn, CI, Occl pl(f,m)), as the ANB angle is increased, there was a strong tendency for the lower incisors to be proclined.

This has been shown in a number of previous studies. (Bjork and Palling, 1954; Solow, 1966; Hasund and Ulstein, 1970; Corelius and Linder-Aronson, 1976; Lundstrom and McWilliam, 1984)
1. L1-FH = 65.2 - 1.70 ANB

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>Stdev</th>
<th>t-ratio</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>65.228</td>
<td>0.987</td>
<td>66.04</td>
<td>0.000</td>
</tr>
<tr>
<td>ANB</td>
<td>-1.703</td>
<td>0.203</td>
<td>-6.39</td>
<td>0.000</td>
</tr>
</tbody>
</table>

\( s = 7.355 \quad R\text{-sq} = 44.5\% \quad R\text{-sq(adj)} = 43.8\% \)

Analysis of Variance

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>1</td>
<td>3811.3</td>
<td>3811.3</td>
<td>70.46</td>
<td>0.000</td>
</tr>
<tr>
<td>Error</td>
<td>88</td>
<td>4760.3</td>
<td>54.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>89</td>
<td>8571.6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. L1-NB = 22.7 + 1.18 ANB

<table>
<thead>
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<th>Stdev</th>
<th>t-ratio</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>22.707</td>
<td>0.948</td>
<td>23.93</td>
<td>0.000</td>
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<tr>
<td>ANB</td>
<td>1.178</td>
<td>0.194</td>
<td>6.04</td>
<td>0.000</td>
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</table>

\( s = 7.065 \quad R\text{-sq} = 29.3\% \quad R\text{-sq(adj)} = 28.5\% \)

Analysis of Variance

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<th>p</th>
</tr>
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<tr>
<td>Regression</td>
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<td>1823.3</td>
<td>1823.3</td>
<td>36.53</td>
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<tr>
<td>Error</td>
<td>88</td>
<td>4392.1</td>
<td>49.9</td>
<td></td>
<td></td>
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<tr>
<td>Total</td>
<td>89</td>
<td>6215.4</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

3. L1-Apog = 25.3 + 0.106 ANB

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>Stdev</th>
<th>t-ratio</th>
<th>p</th>
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</thead>
<tbody>
<tr>
<td>Constant</td>
<td>25.308</td>
<td>0.854</td>
<td>29.61</td>
<td>0.000</td>
</tr>
<tr>
<td>ANB</td>
<td>0.106</td>
<td>0.175</td>
<td>0.60</td>
<td>0.547</td>
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</tbody>
</table>

\( s = 6.365 \quad R\text{-sq} = 0.4\% \quad R\text{-sq(adj)} = 0.0\% \)

Analysis of Variance

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<th>MS</th>
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<th>p</th>
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</thead>
<tbody>
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<td>Regression</td>
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<td>14.77</td>
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<td>0.547</td>
</tr>
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<td>3565.01</td>
<td>40.51</td>
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<tr>
<td>Total</td>
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<td>3579.79</td>
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</tbody>
</table>

**TABLE 4. Regression equations between ANB and various incisor inclination measurements. (cont.)**
4. L1-Mpl = 89.4 + 1.75 ANB

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>Stddev</th>
<th>t-ratio</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>89.370</td>
<td>1.097</td>
<td>81.46</td>
<td>0.000</td>
</tr>
<tr>
<td>ANB</td>
<td>1.7543</td>
<td>0.2254</td>
<td>7.78</td>
<td>0.000</td>
</tr>
<tr>
<td>s = 8.169</td>
<td>R-sq = 40.8%</td>
<td>R-sq(adj) = 40.1%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Analysis of Variance

<table>
<thead>
<tr>
<th>SOURCE</th>
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<th>MS</th>
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<th>p</th>
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<tr>
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<td>0.000</td>
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<tr>
<td>Error</td>
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<td>5872.6</td>
<td>66.7</td>
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<td>Total</td>
<td>89</td>
<td>9916.9</td>
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<td></td>
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</tbody>
</table>

5. L1-CGn = 68.0 + 1.50 ANB

<table>
<thead>
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<th>Coef</th>
<th>Stddev</th>
<th>t-ratio</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>67.9976</td>
<td>0.9503</td>
<td>71.56</td>
<td>0.000</td>
</tr>
<tr>
<td>ANB</td>
<td>1.4974</td>
<td>0.1952</td>
<td>7.67</td>
<td>0.000</td>
</tr>
<tr>
<td>s = 7.076</td>
<td>R-sq = 40.1%</td>
<td>R-sq(adj) = 39.4%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Analysis of Variance

<table>
<thead>
<tr>
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<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>1</td>
<td>2946.5</td>
<td>2946.5</td>
<td>58.85</td>
<td>0.000</td>
</tr>
<tr>
<td>Error</td>
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<td>4405.7</td>
<td>50.1</td>
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</tr>
<tr>
<td>Total</td>
<td>89</td>
<td>7352.2</td>
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</tbody>
</table>

6. L1-Occl(f) = 72.9 - 1.49 ANB

<table>
<thead>
<tr>
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<th>Coef</th>
<th>Stddev</th>
<th>t-ratio</th>
<th>p</th>
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</thead>
<tbody>
<tr>
<td>Constant</td>
<td>72.938</td>
<td>1.032</td>
<td>70.67</td>
<td>0.000</td>
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<td>-1.4887</td>
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<tr>
<td>s = 7.685</td>
<td>R-sq = 35.9%</td>
<td>R-sq(adj) = 35.2%</td>
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</table>

Analysis of Variance

<table>
<thead>
<tr>
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<th>MS</th>
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<td>2912.5</td>
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<td>Total</td>
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<td>8109.6</td>
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</table>

(cont.)
7. L1-Occl(m) = 70.4 - 1.68 ANB

<table>
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</thead>
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<tr>
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<td>70.3544</td>
<td>0.8602</td>
<td>81.82</td>
<td>0.000</td>
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<tr>
<td>ANB</td>
<td>-1.6838</td>
<td>0.1767</td>
<td>-9.53</td>
<td>0.000</td>
</tr>
</tbody>
</table>

s = 6.405  
R-sq = 50.8%  
R-sq(adj) = 50.2%

Analysis of Variance

<table>
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<tr>
<th>SOURCE</th>
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<th>SS</th>
<th>MS</th>
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<td>3725.7</td>
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</tr>
<tr>
<td>Total</td>
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<td>7336.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8. L1-Cl = 92.4 - 1.87 ANB

<table>
<thead>
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<td>0.1967</td>
<td>-9.51</td>
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s = 7.129  
R-sq = 50.7%  
R-sq(adj) = 50.1%

Analysis of Variance

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9. L1-sc-Pog = 160 - 0.983 ANB

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<td>0.2002</td>
<td>-4.91</td>
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s = 7.257  
R-sq = 21.5%  
R-sq(adj) = 20.6%

Analysis of Variance

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<td>Author</td>
<td>No. of cases</td>
<td>Apical base rel.</td>
<td>Dep. var.</td>
<td>Cor. coeff.</td>
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<td>--------------</td>
<td>------------------</td>
<td>-----------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>1. Bjork and Palling, 1954</td>
<td>243 M</td>
<td>ANPog</td>
<td>L1-OL</td>
<td>-0.53</td>
<td></td>
</tr>
<tr>
<td>2. Solow, 1966</td>
<td>102 M</td>
<td>ANB</td>
<td>L1-Mpl</td>
<td>+0.33</td>
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</tr>
<tr>
<td>3. Hasund and Ulstein, 197093 M</td>
<td></td>
<td>ANB</td>
<td>L1-NB</td>
<td>+0.62</td>
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</tr>
<tr>
<td>4. Hasund and Ulstein, 197072 F</td>
<td></td>
<td>ANB</td>
<td>L1-NB</td>
<td>+0.47</td>
<td></td>
</tr>
<tr>
<td>5. Corelius and Linder-Aronson, 1976</td>
<td>60 (M+F)</td>
<td>ANB</td>
<td>L1-Mpl</td>
<td>+0.52</td>
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</tr>
<tr>
<td>6. Lundstrom and McWilliam, 1984</td>
<td></td>
<td>ANB</td>
<td>L1-SN-4</td>
<td>-0.60</td>
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</tr>
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**TABLE 5. Correlation coefficients for associations between the antero-posterior apical base relation and the lower incisor inclinations.**

Lundstrom and McWilliam (1984) stated that variations in the antero-posterior apical base relationship are compensated for in the first place, by proclination or retroclination of the lower incisors and, in the second place, by a reversed angulation of the upper incisors.

The correlation was strongest with L1-Occl(m) and L1-Cl followed by L1-Mpl, L1-CGn and L1-Occl(f).

Intra-mandibular reference planes can be divided into two groups, skeletal planes (Mpl, CGn) based on skeletal landmarks only, and dental planes (Occl pl(f,m), Cl), based on dental landmarks only, or on both skeletal and dental landmarks.

Thus, within the intra-mandibular reference planes, dental reference planes showed higher correlation than skeletal planes. This might be explained in terms
<table>
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<th>Extra-mandibular</th>
<th>Intra-mandibular</th>
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<tr>
<td>horizontal</td>
<td>FH</td>
<td>Mpl</td>
</tr>
<tr>
<td>vertical</td>
<td>NB</td>
<td>Ocol(f,m)</td>
</tr>
<tr>
<td>skeletal</td>
<td>APog</td>
<td>CGn</td>
</tr>
<tr>
<td></td>
<td>NPog</td>
<td>Cl</td>
</tr>
</tbody>
</table>

**Fig. 14. Cephalometric reference lines.**

of reduced effects of vertical skeletal variation on the lower incisor inclination measurement in the case of dental reference planes. Orientation of the dental reference planes tends to be maintained through the process of vertical dental compensation, whereas with skeletal reference planes the skeletal variation is expressed directly in the orientation of the reference planes.

Extra-mandibular planes which are based on more remote landmarks from the jaw bases (FH, NB) also showed similar correlations. (i.e. As ANB is increased, lower incisors tended to be proclined.) This is easily understandable since the landmarks remote from the jaw bases and, thus, the orientation of the reference planes would be minimally affected by the jaw base discrepancy, allowing reasonably consistent registration of dental compensation that has taken place.

NB plane, due to B point as its landmark, is subject to variation with changes in position of the mandible as compared with FH which is unaffected. However, the effect of mandibular positional change is minimized by the relatively large distance between the N and B point. This can be compared with APog line where the
distance between A point and Pog is smaller and, thus, the orientation of the line is more sensitive to the position of the two reference points.

When incisors are related to the extra-mandibular plane based on the jaw bases themselves (A-Pog), they showed no correlation with the ANB changes. This was expected because the dento-alveolar compensation is built into the APog reference line itself. Any change in antero-posterior apical base relationship will automatically change the orientation of the APog line which masks the measurement of dental compensation changes. This was noted by a number of authors previously. (Ricketts, 1957; Williams, 1969; Solow, 1980)

There was a significant but weak correlation between ANB and i-sc-Pog.

5.2.2. Vertical discrepancy (FH-Mpl) vs mandibular incisor inclination

There was no significant correlation between the FH-Mpl angle and the lower incisor inclination measurements regardless of the reference planes used, with the only exception being L1-Mpl. Both intra-mandibular and extra-mandibular reference planes didn't show any significant correlation with the vertical skeletal discrepancy.

The lack of correlation could possibly be reasoned to have arisen from the interfering influence of antero-posterior skeletal variation of the sample, since it is a combination of different subgroups representing vertical as well as antero-posterior skeletal variation. However, the reference planes (NB, APog) that have the antero-posterior skeletal variation built into their orientation also didn't show any significant correlation.

This means that there is no consistent compensatory relationship of the lower incisors to the varying vertical skeletal discrepancy. This finding was contrary to
our expectation of lingual lower incisor compensation to high angle cases and labial lower incisor compensation to low angle cases, as was suggested by Bjork (1963) and Schudy (1963). Although this relationship has been demonstrated in individual cases by Bjork and Schudy, this cannot be predicted reliably due to variable adaptive responses of individual cases.

Bjork (1972) also has found no correlation between L1-SN and SN-Mpl representing growth rotation of mandible.

In the case of L1-Mpl measurement, both variables were topographically related to one another through the reference line Mpl, and can consequently be said to be topographically interdependent. (Solow, 1966; Corelius and Linder-Aronson, 1976) The mandibular plane variation affects both L1-Mpl and FH-Mpl measurements, thus eliminating the factor of Mpl variation from the correlation. The correlation coefficient between L1-Mpl and FH-Mpl was -0.440. This confirms the previous findings by Corelius and Linder-Aronson (1976) who found exactly the same correlation coefficient between L1-Mpl and NL-Mpl for their sample.

Ellis and McNamara (1986), however, found no significant correlation between L1-Mpl and FH-Mpl, but instead, found a very high correlation between L1-FH (and L1-NB, L1-Occl pl) and FH-Mpl.

In this study, contrary to the findings of Ellis and McNamara, there was no significant correlation between FH-Mpl and L1-FH as well as the other incisor inclination measurements.

Corelius and Linder-Aronson (1976) also did not find any significant correlation between L1-NB and NL-Mpl.

The findings of Ellis and McNamara appears to be the result of their study sample
selection based on "normal" relationship of the mandibular incisor to the mandibular plane, with L1-Mpl angle within the 89-93.5 deg. range. This means that they have selected only those cases with minimal dental compensation (as measured in relation to Mpl.) to the skeletal relationships, thus consistently reflecting the positional variation of the mandible in the L1-FH measurement. When this is related to the mandibular positional variation itself, it is not surprising that high correlation would result.

High correlation between L1-NB and FH-Mpl can also be explained similarly.

**5.2.3. AP skeletal discrepancy (ANB) vs mandibular incisor apex position (x/x+y)**

\[ x/y = 44.9 - 0.828 \text{ ANB} \]

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>Stddev</th>
<th>t-ratio</th>
<th>p</th>
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<td>1.282</td>
<td>35.07</td>
<td>0.000</td>
</tr>
<tr>
<td>ANB</td>
<td>-0.8280</td>
<td>0.2653</td>
<td>-3.14</td>
<td>0.002</td>
</tr>
<tr>
<td>s = 9.544</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ R\text{-sq} = 10.1\% \quad R\text{-sq(adj)} = 9.1\% \]

Analysis of Variance

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<td>8916.46</td>
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</table>

**TABLE 6. Regression equation between ANB and x/x+y.**

There was a significant but weak negative correlation between the ANB angle and the lower incisor apex position in the symphysis.

As the ANB angle increased the incisor apex moved closer to the lingual cortical plate.
5.2.4. Vertical discrepancy (FH-Mpl) vs mandibular incisor apex position
(x/x+y)

\[
x/x+y = 30.1 + 0.488 \text{ FH-Mpl}
\]

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<tr>
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<tr>
<td>FH-Mpl</td>
<td>0.4878</td>
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<td>3.51</td>
<td>0.001</td>
</tr>
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<td>s = 9.428</td>
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<tr>
<td>R-sq</td>
<td>12.3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-sq(adj)</td>
<td>11.3%</td>
<td></td>
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Analysis of Variance

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<td>Total</td>
<td>89</td>
<td>8916.5</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**TABLE 7. Regression equation between FH-Mpl and x/x+y.**

There was a significant but weak positive correlation between the FH-Mpl angle and the lower incisor apex position in the symphysis.

As the FH-Mpl angle is increased the apex moved closer to the labial cortical plate.

5.2.5. Mandibular incisor apex position (x/x+y) vs mandibular incisor inclination

1. \[L1-\text{FH} = 43.4 + 0.394 \text{ x/x+y}\]

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<td>x/x+y</td>
<td>0.39353</td>
<td>0.09573</td>
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<tr>
<td>s = 9.040</td>
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<td></td>
</tr>
<tr>
<td>R-sq</td>
<td>16.1%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-sq(adj)</td>
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Analysis of Variance

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**TABLE 8. Regression equations between x/x+y and various incisor inclination measurements.** (cont.)
2. \( L1-NB = 40.6 - 0.339 \, x/\sqrt{y} \)

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<td>( x/\sqrt{y} )</td>
<td>-0.33867</td>
<td>0.08135</td>
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<tr>
<td>( s = 7.682 )</td>
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<td>R-sq = 16.5%</td>
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<tr>
<td>R-sq(adj) = 15.5%</td>
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Analysis of Variance

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<td>Total</td>
<td>89</td>
<td>6215.4</td>
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3. \( L1-AP = 37.1 - 0.271 \, x/\sqrt{y} \)

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<td>( x/\sqrt{y} )</td>
<td>-0.27123</td>
<td>0.06104</td>
<td>-4.44</td>
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<tr>
<td>( s = 5.764 )</td>
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<td></td>
</tr>
<tr>
<td>R-sq = 18.3%</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>R-sq(adj) = 17.4%</td>
<td></td>
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Analysis of Variance

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4. \( L1-Mpl = 122 - 0.645 \, x/\sqrt{y} \)

<table>
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</tr>
<tr>
<td>( x/\sqrt{y} )</td>
<td>-0.64534</td>
<td>0.08892</td>
<td>-7.26</td>
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</tr>
<tr>
<td>( s = 8.396 )</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>R-sq = 37.4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-sq(adj) = 36.7%</td>
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Analysis of Variance

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<td>3713.4</td>
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<td>70.5</td>
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<td>Total</td>
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<td>9916.9</td>
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</table>

(cont.)
5. L1-CGn = 95.1 - 0.532 x/y

<table>
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<td>27.79</td>
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</tr>
<tr>
<td>x/y</td>
<td>-0.53164</td>
<td>0.07847</td>
<td>-6.77</td>
<td>0.000</td>
</tr>
<tr>
<td>s</td>
<td>7.410</td>
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</tr>
<tr>
<td>R-sq</td>
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<tr>
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<td>33.5%</td>
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Analysis of Variance

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6. L1-Occl(f) = 50.3 + 0.426 x/y

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<tr>
<td>x/y</td>
<td>0.42645</td>
<td>0.09093</td>
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<tr>
<td>s</td>
<td>8.586</td>
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</tr>
<tr>
<td>R-sq</td>
<td>20.0%</td>
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<tr>
<td>R-sq(adj)</td>
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Analysis of Variance

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7. L1-Occl(m) = 45.2 + 0.474 x/y

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<td>R-sq(adj)</td>
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(cont.)
8. \( L1-C1 = 64.7 + 0.519 \frac{x}{x+y} \)

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<tr>
<td>( \frac{x}{x+y} )</td>
<td>0.51862</td>
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\( s = 8.709 \quad R\text{-sq} = 26.4\% \quad R\text{-sq(adj)} = 25.6\% \)

Analysis of Variance

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9. \( Li-sc-Pog = 138 + 0.430 \frac{x}{x+y} \)

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<td>( \frac{x}{x+y} )</td>
<td>0.42961</td>
<td>0.07367</td>
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\( s = 6.957 \quad R\text{-sq} = 27.9\% \quad R\text{-sq(adj)} = 27.1\% \)

Analysis of Variance

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When the lower incisors are related to the intra-mandibular reference planes, there was a significant correlation between the apex position and the inclination of the incisors.

As the incisors moved from a retroclined to a proclined position, the apices moved towards the lingual cortical plate.

The correlation was strongest with \( L1\text{-Mpl} \) angle measurement followed by \( L1\text{-CGn}, L1\text{-Occl.pl(m)}, L1\text{-Cl}, L1\text{-Occl.pl(f)} \) angles.

Thus, the lower incisor inclination measurement showed higher correlation with the incisor apex position (\( \frac{x}{x+y} \)) when related to the skeletal reference planes as compared to the dental reference planes.
This confirmed our expectation and is an indication that the skeletal reference planes are better representation of the orientation of the apical base.

When the lower incisors are related to the extra-mandibular planes with distant landmarks from jaw bases such as FH or NB lines, there was a significant but weak correlation.

This was again expected because of the possible extra-mandibular landmark variation which is unrelated to the orientation of the mandibular apical base.

When related to the A-Pog line, there was again a significant but weak correlation with the apex position.

There was a significant positive correlation between the lower incisor apex position and the li-sc-Pog angle.

There are several possibilities of lower incisor compensation to varying antero-posterior skeletal relationships. The lower incisors can tip around the centre of rotation which is often thought to be within the middle third of the root (Utley, 1968; Christiansen and Burstone, 1969; Davidian, 1971), or tip around the root apex, or be bodily displaced labio-lingually as we might get an impression in certain clinical situations.

These are represented diagrammatically in Fig. 15.

The results of this study indicate that the lower incisors, as they adapt to the antero-posterior skeletal discrepancy, they do so with tipping movement with reciprocal root apex movement in the opposite direction. This might be interpreted as an indication that the labio-lingual bodily movement of the lower incisors is an unnatural tooth movement even if the root apex position is maintained in the centre of the alveolar base.

The situation that this may be required can be pictured where the lower incisors
Fig. 15. The possibilities of lower incisor compensation to varying antero-posterior skeletal relationships. A. tipping around the root apex. B. tipping around a centre of rotation within the middle third of the root. C. bodily displacement.

are proclined with apex close to the lingual cortical plate in a low angle case with a very broad symphysis. One might wish to torque the roots labially and bodily displace the lower incisors forward in this situation.

Physically, for a given incisal edge displacement, any sort of bodily movement would involve more root movement through bone than tipping movement, thus increasing the likelihood of alveolar bone strain within the alveolar bone itself as well as within the overall soft tissue environment. (Fig. 16)

Tipping movement would be more efficient to achieve the desired mandibular incisor crown position with minimal disruption of the alveolar bone, and this appears to be what happens with natural dental compensation.

This is another example where the nature is designed to take care of itself in a most efficient manner.
Fig. 16. Labio-lingual tipping vs bodily displacement of a lower incisor. The bodily displacement involves more root movement through bone than tipping movement.

5.2.6. The range of mandibular incisor root apex positions.

The apex position varied from 17.1% to 66.3%.

The mean and standard deviation were 42.45+/-10%.

However, this might not represent the population mean because of the sample selection process where sample subgroups were decided first and the required number of cases filled. There was also an uneven distribution of subgroups due to our difficulty in finding cases for the subgroup of Class III low angle malocclusion. The aim was to represent wide range of skeletal configuration in both vertical and antero-posterior planes for the correlation purposes rather than to represent the population.

The range of variation of the lower incisor apex position was very high for a given
inclination, despite the high correlation between the apex position and the inclination measurements.

This might be an indication of another factor or factors operating to influence the position of the incisor apices within the apical base or the measurement of this position.

For example, any component of labio-lingual bodily displacement of lower incisor segment under the influence of soft tissue pulling against them with growth, is a possible factor contributing towards this variability.

There is also the variability of the reference planes themselves for the measurement of inclination.

Although fairly severe Class III cases were included in the study, the position of the lower incisor apices didn't exceed 70% position in the apical base.

In cases with proclined incisors on the other hand, the apex position didn't move beyond 17% position despite the fact that there were severely proclined cases.
6. SUMMARY and CONCLUSION

The lower incisor axial inclination and apex positions were measured in a sample of 90 subjects, ranging from 12 yrs. to 28 yrs. of age with a mean age of 15.3 yrs.

All Classes of malocclusions were represented, including Class I, Class II and Class III skeletal types as well as high, normal and low angle vertical facial types. The axial inclinations were measured in relation to various cephalometric reference planes which were classified into intra-mandibular and extra-mandibular reference planes.

Intra-mandibular reference planes are those based only on intra-mandibular landmarks whereas extra-mandibular planes are based on one or more extra-mandibular landmarks.

Intra-mandibular planes are then subdivided into skeletal and dental planes. Reference planes based only on skeletal landmarks are defined `skeletal', while those involving one or more dental landmarks are defined `dental'.

Extra-mandibular planes are also subdivided into horizontal and vertical planes according to their orientation in the film.

1. When the incisors were related to the intra-mandibular reference planes (Mpl, CGn, CI, Occl pl(f,M)), there was a high correlation between the ANB angle and the incisor inclination measurements. As the ANB angle is increased there was a strong tendency for the lower incisors to be proclined.

Within the intra-mandibular reference planes, dental reference planes showed higher correlation with the ANB measurement than the skeletal
planes. This was thought to result from the reduced effects of vertical skeletal variation on the lower incisor inclination measurement in the case of dental reference planes due to the process of vertical dental compensation.

Extra-mandibular reference planes based on more remote landmarks from the jaw bases (FH, NB) also showed similar correlations.

The extra-mandibular reference plane based on jaw bases themselves (APog) did not show any significant correlation with ANB measurement. This was expected because the dento-alveolar compensation is built into the APog reference line itself.

2. There was no significant correlation between the FH-Mpl angle and the lower incisor inclination measurements, regardless of the reference planes used, with the only exception of L1-Mpl.

This means that there is no consistent compensatory relationship of the lower incisors to the varying vertical skeletal discrepancy. Although a compensatory relationship has been demonstrated in individual cases, this relationship cannot be predicted reliably due to variable adaptive responses of individual cases.

3. There was a significant but weak negative correlation between the ANB angle and the labio-lingual lower incisor apex position in the apical base.

4. There was a significant but weak positive correlation between the FH-Mpl angle and the labio-lingual lower incisor apex position in the apical base.

5. When the lower incisors were related to the intra-mandibular reference planes, there was a significant correlation between the apex position and the inclination of the incisors. As the incisors moved from a retroclined to
a proclined position, the apices moved towards the lingual cortical plate. Skeletal reference planes showed higher correlation than the dental reference planes, indicating that the skeletal reference planes are better representation of the orientation of the apical base. When the lower incisors were related to the extra-mandibular planes with distant landmarks from jaw bases, there was a significant but weak correlation. When the lower incisors were related to APog line, there was, again, a significant but weak correlation with the apex position.

These results indicate that the lower incisors, as they adapt to the antero-posterior skeletal discrepancy, do so with tipping movement with reciprocal root apex movement in the opposite direction.

6. The apex position varied from 17.1% to 66.3%. The mean and S.D. were 42.45+/-10.

This shows the tendency of lower incisor root apices to be positioned more lingually within the apical base. The labial limit of the apex position, as measured by the distance from the labial cortical plate to the incisor apex, was twice as large as the lingual limit. The range of variation of the lower incisor apex position was very high for a given inclination, despite the high correlation between the apex position and the inclination measurements. This is an indication of another factor or factors operating to influence the position of the incisor apices or the measurement of this position. There is
also the factor of the lower incisor inclination measurement variability.

From these findings, several points of clinical application can be drawn. In our attempt to treat antero-posterior skeletal discrepancy cases by dental compensation or decompensation, the identified pattern of naturally occurring dental compensation can be simulated. This is thought to take place by tipping movement with reciprocal root apex movement in the opposite direction. Labio-lingual bodily movement or root torquing movement of lower incisors is thought to be undesirable for the integrity of the supporting alveolar bone. Physically, for a given incisal edge displacement, any sort of labio-lingual bodily movement would involve more root movement through bone than tipping movement, thus increasing the likelihood of alveolar bone strain within the alveolar bone itself as well as within the overall soft tissue environment. Furthermore, contrary to the popular belief that the incisor root apices should ideally be centred in the apical base at the end of treatment, it was found that, in untreated dentitions, the apex position varied depending on the amount of dental compensation that has already taken place. Therefore, in our treatment of individual cases that require dental compensation, it would be biologically more desirable to position the lower incisor apices according to the compensation requirements rather than to centrally place them in all situations. Central placement of roots in certain situations may cause unnecessary disruption of the alveolar bone.

It is, perhaps, also wise to avoid exceeding the limits of naturally occurring apex positions in the symphysis in our attempt to camouflage skeletal discrepancy. Future studies can examine the long-term effects of exceeding these limits of
incisor apex positions, and compare the cases treated beyond the limits with the cases treated within the limits.
The findings of this study also make it apparent that the cephalometric measurements used to determine the lower incisor position and inclination should be only used with a full understanding of the variables that may affect the measurements. On an individual basis, the measurements based on various cephalometric reference planes provide useful information, but the various confounding factors should be taken into consideration in their interpretation.
In assessing existing antero-posterior dental compensation, as might be necessary in surgical cases where decompensation is required, intra-mandibular reference planes are useful. Skeletal planes are better representation of the orientation of the apical base while the dental planes have some vertical dental compensation incorporated in their orientation.
In determining the lower incisor position according to the dental compensation requirements, the vertical extra-mandibular reference plane (APog), representing the jaw bases themselves, is probably the most useful plane.
Table 9. Cephalometric measurements.
Fig. 17. Plot of mandibular incisor inclination measurements against ANB measurements.
Fig. 18. Plot of mandibular incisor inclination measurements against FH–Mpl measurements.
Table 12. Cephalometric measurements—sorted according to x+y measurements
Fig. 19. Plot of mandibular incisor inclination measurements against x/x+y measurements.
Fig. 20. Plot of $x/x+y$ against ANB and FH–Mpl measurements.
8. BIBLIOGRAPHY


819.


Osborne, J.W. (1961): Investigation into the interdental forces occurring between the teeth of the same arch during the clenching of the jaws. Arch. Oral Biology. 5:202-211.


Ricketts, R.M., Bench, R.W., Gugino, C.F., Hilgers, J.J., Schulof, R.J. Bioprogressive therapy-Book 1. RMO.


cephalometric appraisal of first premolar extraction cases treated by traditional edgewise orthodontics. Am. J. Orthod. 87:27-38.


Orthod. 36:813-830.


