A STUDY OF MANDIBULAR ANTERIOR CROWDING IN UNTREATED CASES AND ITS PREDICTABILITY

by

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Abstract

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Despite long standing interest in the subject of incisor crowding, no comprehensive understanding of the quantatative changes in incisor alingment during normal growth and development in the untreated population exists. Accordingly, the purpose of this study is to identify and quantify those changes in incisor crowding that takes place in the mandibular dental arches of untreated individuals. These changes are evaluated from measurements of dental casts and lateral headfilms of 50 individuals at ages corresponding to pretreatment and at least 3 years post-retention. Incisor Irregularity is quantatatively measured at each observation and related to specific anatomic and cephalometric conditions in the face and dental arches. Study model parameters as well as anatomic and cephalometric variables at both the initial and final observations are evaluated for their relationship to crowding. Additionally, sex, age and Angle classification are evaluated for their contribution to crowding. A series of statistical tests (Pearson's Correlation Coefficients, Multiple Stepwise Regression and Discriminant Analyses)

were employed to accurately analyze the interaction of these variables. Finally by analyzing variables from the 12 year old observation with a Discriminant Function Analysis, linear combinations of discriminating factors were constructed to predict the direction and the severity of crowding that occurred at 18 years of age.

The findings of this investigation suggest the following conclusions:

(1) No statistically significant relationship exists between incisor crowding and gender or Angle classification.

(2) Arch length, cuspid width and molar width changes were found to be insignificant factors in controlling crowding, but may contribute in small measure to a multidependent relationship which is associated with crowding.

(3) Incisor irregularity of the whole sample tended to increase with time, but nearly a third of the cases actually showed improvement in incisor alignment.

(4) No single variable measured at either observation time, or the change in any single variable between observations correlate significantly with crowding changes.

(5) Data obtained at 12 years of age can be used to predict with almost 70% accuracy whether incisor alignment will improve or worsen by age 18.

(6) In those individuals whose incisors do crowd, the severity of the crowding increase can be forecast with an accuracy of better than 90%.

(7) Prediction of the magnitude and direction of incisor alignment changes at 18 is independent of the degree of crowding at age 12.

(8) The factors responsible for a natural correction of irregularity appear to be different than those responsible for an increase in the severity of crowding.

(9) A highly complex and intricate interaction of numerous craniofacial and dental matrices are involved as factors predisposing to crowding during the normal growth process.

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DEDICATED

To my Aunt and Uncle, Boots and Frank Nutis, who have been the parents I never had and who have given me love and affection and moral support when I needed it.

"We can put the teeth where we think
they belong, but nature (function)
will eventually place them where
they belong."

John Mershon, 1927

INTRODUCTION

> We may possess high ideals in regard to the relations which the teeth and dentures should bear to each other and to the facial outlines. We may be able with our facilities and chosen methods to move the teeth in a manner and to positions which fulfill all the requirements of our understanding of perfect correction; and we may be justly proud of the really wonderful results which we, at times, are able to accomplish. But after all, what does this temporary pleasure and satisfaction to ourselves and our patients amount to, if we find in a few years that the very cases which create in us the greatest pride, are going back to their former malpositions and disharmonies, in spite of everything we have been able to do with retaining appliances.
>
> Calvin Case (1920)

Crowding in the anterior dental segments is generally defined as incisor irregularity and is associated with a high degree of skeletal and dental variability from individual to individual. First observed on skulls of prehistoric man, this condition has continued in mankind to the present day. Orthodontists, over the past century, have attempted to rid individuals of the problem, but have only been able to develop methods for treating the symptoms. Needless to say, we do not yet have a real understanding of the biological basis for this condition. It is no wonder that post-retention stability of the anterior segment is such a dilemma and has become such a controversial topic among orthodontic theorists when the extent of post-treatment crowding actually approaches if not exceeds the amount of pre-treatment crowding.

Not only has crowding been observed in post-treatment orthodontic cases, but, of course, it is also a major blemish on the dentition of untreated individuals. There are certain basic questions which spring to mind when pondering this problem. Which particular individuals are most susceptible to crowding? What is the prognosis in different categories of individuals? Are there disparities between age, sex and molar classification? Is there an interaction of these and other similar factors? Are there certain primary, underlying anatomic and physiologic factors that are usually responsible, or is crowding essentially only a "dental" problem, or perhaps some combination? What will be the nature of the dental change; who will remain unchanged with continued growth; who will get worse; or even perplexing, can anyone get better without treatment? The ability to answer some or all of these questions would enable the orthodontist to comprehend much more of the developmental basis for crowding than is presently known and could serve as a useful adjunct in determining the value of his therapy.

For centuries, crowding of the mandibular incisors has been viewed as the most frequent anomaly of the adult dentition (Berger, 1965). Early pioneers of dentistry such as Fairchild (1728), Mogitot (1867), Davenport (1887) and Angell (1860), recognized problems of crowding or jumbling of incisors and speculated various philosophies toward achieving stabilization of the anterior segment. These men formulated the foundation for our present-day knowledge of tooth placement and the significance of normal occlusion. According to Goldstein (1965), they were also the first to recognize that there

was a possible interdependence between factors associated with craniofacial growth and dentitional changes.

In the early years of orthodontics, one of the most controversial aspects with regard to crowding was the nature of dimensional changes within the growing dental arch. McCauley (1944) is generally given credit as the first to recommend to the clinician that maintenance of pre-treatment intercanine and intermolar widths during therapy would contribute to denture stability. Strang (1952) went so far as to say that these arch dimensions are the true indices of muscular balance and must not be tampered with. In addition, Strang felt that expansion of the canine or molar dimensions would condemn the denture to certain and irrevocable relapses. Orthodontic research for the next 30 years was marked by a plethora of attempts to test the validity of this theorem. These attempts comprised two major approaches: observation of orthodontically-treated non-extraction and extraction cases, and observations of untreated orthodontic cases.

In order to determine and differentiate those occurences stimulated by orthodontic treatment from those changes which would have occured through growth alone, a controlled scientific study of the untreated dentition and its dynamic alteration through time is clearly a preliminary step which has yet to be accomplished. Therefore, the purpose of this investigation to measure quantitatively incisor irregularity at ages corresponding to pre-treatment and at least 3 years post-retention. Where possible, the measurements will be related to anatomic, skeletal and dental cast landmarks.

Further, the changes in incisor irregularity as they relate to growth and development will be determined. Finally, a method of predicting the magnitude and direction of crowding at 18 based upon the factors measured at the original cephalogram and study models will be devised.

REVIEW OF THE LITERATURE

Orthodontically Treated Extraction and Non-Extraction Studies

With the invention of the Bolton-Broadbent cephalometer in 1931, it became possible to evaluate the clinical observations of Angle, Case, McCauley, Strang et al. (Reidel, 1975). Nance (1947) studied the permanent dentition which had been out of retention for various periods of time. He concluded:

1. that to attain a stable permanent result, mandibular teeth must be positioned properly with respect to basal bone;
2. that only limited amounts of arch length can be permanently gained;
3. that proper positioning of mandibular incisors requires careful case analysis;
4. that only in a limited number of cases can a small amount of buccal expansion be tolerated.

Litowitz (1948) examined 20 non-extraction, orthodontically treated cases 1 to 5 years out of retention only to find that the mandibular incisors tend to return to their original positions. Additionally, he found that the lower arch length decreased while lower arch dimensions and molar and cuspid widths also decreased during the post-retention period. Dona (1952), in a study of 22 cases out of retention between 2 and 6 years, found that intermolar and intercuspid widths have a tendency to return to their original dimension if expanded during treatment. It was also noted that overbite has a very strong tendency to relapse, while arch length has a

corresponding tendency to decrease after treatment. Stachler (1958), in 20 Class II, Division I extraction cases, found that after treatment, the overbite correction has a tendency to return while mandibular incisors show some degree of overlapping.

Walter (1953) examined casts of 102 non-extraction orthodontically treated subjects between ages 6 and 36. After making arch measurements on pre-treatment and post-retention casts, Walter concluded that the concept in which the dental arch cannot be permanently widened or lengthened is incorrect. He also implied that if there is a decrease in these arch dimensions, mandibular crowding will result.

In a study of 28 orthodontically treated cases, Kelly (1959) showed that expanded intercanine dimension during treatment tended to return to its original dimension, resulting in crowding of the lower anterior teeth. However, no quantitative cast measurements of irregularity were made in this study. Furthermore, Kelly theorized that the relapse that was evident in the majority of the cases studied was primarily related to factors other than craniofacial growth, such as tooth size discrepancy, habits, thoroughness of treatment, patient cooperation and failure to establish the same arch form and size.

Steadman (1961) studied 31 cases out of retention one or more years and concluded that the intermolar and intercuspid distances were dependent upon the dictates of the balance of forces produced by the muscle function and growth of the individual. Consequently, he reasoned that crowding results directly from post-treatment decreases of the intermolar and intercuspid dimensions which had been expanded during treatment.

In response to Steadman's work, Walter (1962) (vida supra) decided to attempt validation of Steadman's recent findings based upon a larger sample size. This new study was conducted on 50 extraction and 50 non-extraction cases at least 2 years out of retention. Contrary to Steadman, Walter concluded that both extraction and non-extraction cases could maintain a modest increase in intermolar and intercanine dimensions post-retention. Walter summarized his discussion by prophesizing: "It appears the ultimate study is yet to be done. Such an investigation would perforce an analysis of all the important variants gleaned from casts and cephalometric data."

Arnott (1962, 50 non-extraction cases) and Arnold (1952, 30 extraction and 20 non-extraction cases) studied patients who were at least 5 years post-retention and both men concluded that intercanine and intermolar widths have a tendency to return to pre-treatment levels, and overbite which was decreased during treatment has a tendency to relapse. In similar fashion, Lombardi (1972), examining 30 extraction and non-extraction cases treated to Tweed specifications, deduced that crowding occurs after treatment if the mandibular intercanine width had been increased during treatment.

Welch (1965), in a study involving 34 extraction cases at least 5 years out of retention, showed that arch width increases during treatment tend to relapse. A notable finding of this study is that the amount of increase in post-treatment overbite is significantly related to the amount of decrease of the intercanine width following treatment.

In a 10-year post-retention study, Shapiro (1973), analyzed 80 casts of non-extraction and extraction cases to disclose longterm post-orthodontic effects upon the dentition. Shapiro's findings demonstrate that, as expected, the intermolar and intercuspid widths had a remarkable tendency to return to the pre-treatment dimension. However, in spite of this the Class II, Division II post-treatment subjects demonstrated an ability to maintain a treatment expansion of the intercanine dimension.

Gallerano (1976), in a follow-up paper, examined 83 extraction and non-extraction cases out of treatment at least 10 years by means of a quantatative method of measuring incisor irregularity on study models. Even Gallerano recognized that, unfortunately, his study is severely limited by not using cephalometric data. Despite previous findings, Gallerano nonetheless concludes that the post-treatment decrease of the intercanine dimension is not related to the ensuing crowding. His results indicate that the intercanine dimension ceases to decrease after the third year post-treatment while the degree of incisor irregularity continues to increase for a much longer period of time. Other pertinent and related findings were:

1. that decreases in arch length in extraction cases from post-treatment to post-retention is not associated with an increase in crowding at post-retention;

2. that females tend to show slightly more net correction of crowding than males;

3. that cases with the highest degree of pre-treatment crowding also exhibit the highest degree of post-treatment crowding;

4. that there was a net improvement in the alignment of the lower anteriors as a result of orthodontic treatment.

The majority of these studies tend to indicate that any therapeutic expansion of apical base dimensions, such as arch length, intermolar width or intercanine width due to treatment will eventually be decreased with time, if not return fully to their original pre-treatment values. All experimental data to date have been gathered simply by analyzing and observing either the individual patient or their corresponding plaster models. In addition, with the notable exceptions of Shapiro who analyzed arch length through the use of the optocon (designed by Van der Linden, 1971), and Gallerano who employed the use of Helios calipers to accurately measure incisor irregularity, there have been no studies using sophisticated instrumentation to quantify the related data. Interestingly enough, while the need to incorporate additional cephalometric anatomic data with cast data has been direly stressed by previous investigators, there has as yet been no effort at all to satisfy this need. Gallerano emphasizes that no significant conclusion can be reached until cephalometric variables are correlated with counterpart cast data, since the positions of teeth are simply a reflection of the craniofacial matrix in which they exist. Reidel (1969) best typifies the "state of the art" understanding of relapse with the simple statement that, "Teeth that have been moved tend to return to their former positions." Goldstein, in reflecting on over 20 years of practice observes that, "the denture at retention although it may articulate perfectly according to every criteria known, still has a long way to go before it

reaches the equilibrium point."

Changes in Untreated Individuals

Orthodontic therapy for the most part is intentionally initiated while the face is still being influenced by the processes of growth and development. Many investigators believe that growth can be controlled somewhat by treatment to produce favorable anatomic and dental results. On the other hand, there are cases in which treatment goals and normal growth are at odds with each other, and the operator actually finds himself working against growth mechanisms (Enlow, 1975). By simply studying the untreated individual it is possible to exclude the treatment effects and thereby deal directly with changes associated with the processes of growth and development.

In a longitudinal study of dental development between ages 3 and 18 years, Moorrees (1959) found that intermolar distance increases between the 9th and 14th year in both sexes. Also, there is a net decrease in overbite with increasing age. Arch length decreases in males and females with the greatest decrease again occurring between 9 and 14 years. Crowding is noted to increase with age, but this is not quantified. Nance (1947) found that the mandibular first permanent molar shifts forward in the transition from the primary to the permanent dentition, resulting in a 1.7 mm arch length decrease.

Using serial casts of 51 children, Barrow and White (1952) noticed that the intercanine dimension decreases steadily in the

range from 0.5 mm to 1.5 mm after the age of 14. The molar dimension decreases an average of 0.9 mm from ages 11 to 15, and further decreases between 15 and 17 years of age. Crowding was noted to increase with age. However, this study again had no real way for precisely quantifying irregularity. Arch length was observed to decrease continually through the 18th year. In spite of large individual variations, overbite was found to be very stable in the permanent dentition.

Sillman (1964) in a longitudinal study of 65 individuals from birth to 25 years, noted decreases in arch length, intermolar and intercanine dimensions despite large individual variations. In a similar study of 26 individuals between ages 12 and 26, DeKoch (1972) observed arch depth and width and found that arch depth decreased through the transitional dentition period and then continued to decrease at a declining rate at ages 15 to 26. Moreover, DeKoch deduced that crowding in the mandibular incisor area was at least partially related to the decrease in arch depth after age 15 and even after age 17.

In a comprehensive longitudinal study of the teenage dentition, Brown and Dauggard-Jensen (1951) showed decreases in the intermolar, intercuspid and the arch length dimensions. Lundstrom (1968) studied changes in arch dimension in 41 pairs of twins. He concluded that a reduction of dental spacing resulting in an increase of crowding is normal within the growing dentition. Consequently, he reasoned that the increase in crowding is due more to a reduction in the

antero-posterior dimension than in the transverse arch dimension.

Although overbite has been studied by many authors, probably the most exhaustive investigation was done by Björk (1953) who recorded tremendous individual variability in his sample of 322 Swedish males. Deep bite cases exhibited a much greater tendency to open than did normal overbite cases. In general, Björk showed that overbite decreases with increasing age--a tendency which Moorrees (1959) showed to be valid. In 70% of the untreated sample of Brown and Daugaard-Jensen (1951), overbite decreases ranged from 0.5 to 1.95 mm. In addition, a strong tendency for crowding was observed with increasing age. Crowding was measured qualitatively in terms of pluses and minuses.

Fastlicht (1970) studied 56 Ann Arbor school children to evaluate overbite and crowding. On the average, overbite was less among untreated than treated individuals. Crowding was assessed quantitatively to the nearest 0.1 mm. Crowding of the mandibular incisors was determined to be greater in untreated individuals and was significantly greater in males. The mesiodistal width of the lower incisors appeared to be associated directly with crowding. Furthermore, correlations between overbite and crowding showed that with more overbite there was more crowding.

Lavelle (1969), on the other hand, in a cross-sectional sample of 328 British individuals, found that females had significantly more crowding than males. In addition, Lavelle found sex differences in arch length, with males showing a significantly greater length. Lavelle criticized preceding studies which had

utilized qualitative rather than quantatative results to assess irregularity responses.

In summary, through studies of untreated individuals, normal growth and development changes have been shown to relate to arch dimension parameters and crowding. In general, the intermolar dimension, intercanine dimension, arch length and overbite tend to decrease with age. Crowding continues to have an interrelation with these parameters in the untreated dentition, and an increase in crowding is noted with advancing age up to the period of facial maturity.

Other Possible Factors Involved in Incisor Irregularity

Although it is not within the scope of this study to discuss fully all the various theories for crowding, some of the major ideologies not already discussed are relevant. Some of these philosophies are still popular while others have fallen into obscurity. It is safe to say, however, that at this time there is no universally accepted philosophy to explain the ultimate cause(s) of incisor irregularity.

Kinglsey is generally credited for fathering the occlusal school of thought as early as 1880. He stated that the nature of the occlusion of teeth is the most potent factor in determing their stability in a new position. He developed a sizeable following of such noteables disciples as Angle, Jackson, Lisher, Hawley, Hellman and Mershon.

A second school of thought, arose from Lundstrom's (1925) belief that the apical base controls the stability of the denture. Many of the investigators already cited belong to this group. The crux of the apical base theory is that pre-treatment intermolar and intercanine widths are inviolate and that expansion of these dimensions will lead to denture instability resulting in incisor irregularity (McCauley, 1944). Moreover, according to this theory increases in arch length during therapy, or physiologic shortening of arch length in untreated individuals will ultimately result in incisor irregularity.

The mandibular incisor school is attributed to Tweed (1944) and Grieve (1944). They proposed that the lower incisors must be upright and centrally situated over basal bone. Furthermore, the proper angulation of the lower incisor to the mandibular plane when centered in the mandibular symphysis will dictate the stability of the denture.

The musculature school of thought was developed by Rogers in 1922. This ideology stressed the necessity of a proper functional muscle balance to insure stability of the denture. This philosophy was furthered by Brodie and others in the 1940's and 1950's.

Begg (1977), in a study of Aboriginal skulls, noted several constant features of the denture; mesiodistal and occlusal attrition, shortening of arch length and a notable lack of denture irregularity. Begg felt that the etiology of attrition was the coarseness of the Aboriginal diet, the teeth remained regular in spite of the physiologic mesial drift of the denture. Regularity was maintained because of the

coordinated rates of arch length and tooth attrition. Based on these findings Begg hypothesized that irregularity in "civilized populations is at least partially attributable to the loss of coordination between the rates of arch length loss and mesiodistal tooth attrition; i.e., the disparity in rates between Aboriginal and contemporary populations arises more from the refinement of the modern diet and the resulting decrease in tooth attrition than from any changes in physiologic mesial drift.

In addition to these philosophies there are other various anthropologic, craniofacial and geneological theories that have given rise to further speculation as to the basic causes of irregularity. Most of these proposals are outgrowths of one or more of the preceding theories. These hypotheses for the most part remain to be proven.

Berger (1959) views crowding of the mandibular incisors mainly as a result of the evolutionary process. According to this view, crowding should be regarded as an adaptive response to changed phylogenetic conditions, i.e., as an incisor-positioned adaptation to provide equilibrium of static and dynamic forces.

Hooten (1947) believes that there is an evolutionary trend toward a dimunition of growth of the facial skeleton without a corresponding change in tooth dimensions. This theory has been recently supported by Moore, Lavelle and Spence (1968) who compared Neolithic mandibles and teeth to those of modern man. Brash (1956) suggests that the high degree of incisor irregularity in contemporary populations, as compared to primitive populations, is a consequence

of the consistency of the diet. An additional theory by Brash (1956) suggests that malocclusion may be due to severe skeletal disharmonies which have resulted from diverse intermingling of peoples of dissimilar genetic backgrounds.

Lundstrom (1951) has presented evidence for the independent genetic control of tooth size and jaw size. Highley (1967) believes that tooth positions are the results of all the forces acting upon them. In particular, conditions which lead to crowding are potentiated when the combined mesiodistal widths of the upper incisors are too small to be compatible with the breadth of the lower anteriors, or when the combined mesiodistal widths of all the teeth are too great to be compatible with the dimensions of the basal bones.

Björk (1969) believes that mandibular rotation during the growth period is a possible cause of incisor irregularity. In this landmark study, Björk reports that the lower incisors are functionally related to the upper incisors through occlusion. The interincisal angle usually changes less than the rotation of the mandible, and rotation displaces the paths of eruption of all the teeth in a mesial direction. This leads to a crowding of the anterior segments, with subsequent decrease in arch depth. Schudy (1965) discusses "counterclockwise" rotation of the mandible. According to him, this effect occurs when horizontal growth is greater than vertical growth and results in an increase in overbite. Consequently, when the lower incisors are caught between upper anteriors and the rotational placement of the mandible, lower incisor irregularity increases.

Schaeffer (1949), in a survey of 47 untreated individuals from the Broadbent-Bolton files, studied the axial inclinations of lower anterior teeth. He noted a trend toward uprighting of incisors with advancing age, but also found that there was a wide range of individual variations. More importantly, he found in every case regardless of the behavior of their original axial position, the incisors came to occupy a relatively more posterior relation to their supporting bone as the facial skeleton grows. Sanin and Savara (1973) also acknowledge the relation of growth to mandibular crowding. They support Björk's viewpoint that horizontal and vertical growth can affect the position of the lower incisors. Consequently, they believe that the axial inclination of the lower molars and incisors are related directly to the direction of growth of the mandible. The axial inclination of these teeth coupled with the direction of growth of the maxillary and mandibular complexes appear to be major contributors to the development of crowding. In view of these particular findings, it is easy to understand why Mills (1968) believes that the lower anterior teeth lie within a very narrow zone of stability which can be easily disturbed.

Proposal and Rationale

The purpose of this study is to identify the particular quantatative changes relating to incisor crowding that have taken place in the mandibular arches of untreated individuals by means of evaluating their dental casts and lateral headfilms at ages corresponding to pre-treatment and at least 3 years post-retention.

Incisor irregularity is quantitatively measured at each observation and then related to certain specific anatomic and cephalometric conditions in the face and the dental arches. Study model parameters are represented by intercanine width, intermolar width, arch length and Curve of Spee. The anatomic and cephalometric variables are: Frankfort-mandibular plane angle, horizontal alveolar and corpus bone lengths, cranial base rotations, lower incisor-to-mandibular plane angle, and the relation of A point, B point and occlusal plane to sella-nasion. Furthermore, sex, age and Angle classification are also taken into account as they relate to incisor irregularity. Attempts are made to accurately predict the factors that will be responsible for the rebound phenomena developing in post-treatment cases. In essence, there will be an attempt to isolate the morphologic factors that associate with relapse and to determine if these factors are, in fact, a result of normal growth and development or, conversely, a "rebound" effect caused by the treatment procedure itself.

METHODS AND MATERIALS

Source

The cephalograms and models analyzed in this investigation were obtained from the files of the Broadbent-Bolton Center of Case Western Reserve University, School of Dentistry.

Sample

A sample of 50 untreated subjects consisting of 20 Angle Class II Division I cases and 30 Angle Class I cases were studied. These cases were selected at random without regard to sex, facial profile or crowding of the incisors. Each subject satisfied the following requirements:

1. Each case was observed at two time periods. The initial observation corresponded to that of the pre-treatment orthodontic phase. At this point the cases were selected on the basis that the permanent first bicuspids and canines of the lower arch had fully erupted into occlusion. The final observation corresponded to the period of the post-retention phase of orthodontic therapy. From this group no one was selected younger than 17 years of age. The mean ages for these 2 observations were 12.2 and 18.8 years, respectively.

2. With the exception of the third molars all cases studied displayed a full compliment of teeth.

3. Orthodontic therapy had not been initiated on any of these individuals.

4. Cases displaying supernumery teeth or presenting an open bite at either observation were disqualified from the sample.

5. At each observation, initial and final, both a lateral cephalometric headfilm and a correspondent plaster model were analyzed.

6. Individual occlusion was either one of two types, Angle Class I or Angle Class II Division I based on molar relationships.

Technical Details

The cephalograms were taken with the Western Reserve Broadbent-Bolton Cephalometer, as described by Broadbent (1931). Tracings were made in pencil (2H) on 0.003" frosted acetate. Angular measurements were recorded to the nearest degree with a Baume protractor (Unitek Corporation, Monrovia, California). Linear measurements were read to the nearest 0.1 mm with dial vernier calipers (Helios Dial Calipers, DCA Corporation, Washington, D.C.). Incisor irregularity was recorded using Helios calipers according to the method devised by Little (1975), which is accurate to 0.1 mm.

Measurements

Headfilms for each observation were traced and measured consecutively so as to minimize errors. Further, models at both observations were also analyzed consecutively to mitigate model measurement error. All measurements were made by one observer. One month after all measurements had been completed, 20 cases were selected for measurement verification. No significant differences were noted in either the tracings or model measurements.

On the initial and final cephalograms, 10 individual measurements were made, 7 angular and 3 linear (overbite, corpus and alveolar length difference). On the initial and final plaster casts, 5 individual measurements were taken, 4 linear and 1 descriptive (Curve of Spee). The angular measurements are presented

in Table I, linear in Table II and descriptive measurements in Table III (See Figures 1-11). In Appendix I, the various anatomic landmarks and cephalometric planes are defined. Coding coefficients for sex, angle classification and Curve of Spee is presented in Appendix II.

Statistical Methods

Observations were statistically analyzed using an SPSS (Statistical Package for the Social Sciences) program. The entries were coded on the IBM key punch cards which were then verified for use in the computer analysis. Computer analyses were performed on a Univac 1108 computer (Chi Corporation division of Ecotran, Cleveland, Ohio).

The following analyses were utilized in this study:

1. Descriptive Analysis--Compilation of raw data indicated by group means, percentages and standard deviations for each variable.

2. Univariate Analysis of Variance--one-way analyses of variance testing equality of group means on a single discriminating variable, performed for each variable.

3. Factorial Analysis of Variance--two-way analysis of variance testing equality of group means using two variables. Interaction of the various factors are analyzed to determine existence of main effects.

4. Pearson's Correlation Coefficients--analysis of all variables to determine significance and direction of any relationship between two variables.

5. Multiple Stepwise Regression Analysis--an analysis used to determine which of the independent variables is actually accounting for the majority of the variance in the dependent variable. Multiple regression techniques are used to determine the magnitude of direct and indirect influence that each variable has on other variables that follow it in the presumed casual order. The general form of the regression is:

TABLE I

ANGULAR MEASUREMENTS

Measurement	Definition
Sella-Nasion-A Point Angle (SNA)	Angle formed by the intersection of Sella-Nasion plane and a line connecting Nasion and A point.
Sella-Nasion-B Point Angle (SNB)	Angle formed by the intersection of Sella-Nasion plane and a line connecting Nasion and B point.
A point-Nasion-B Point (ANB)	Angle formed by lines NA and NB at Nasion.
Frankfort Mandibular Plane Angle (FMA)	Angle of mandibular plane in relation to Frankfort horizontal.
Occlusal Plane Angle (SNFOP)	Angle formed by the junction of Sella-Nasion and the functional occlusal plane.
Incisor Mandibular Plane Angle (IMPA)	Angle of the mandibular plane in relation to a line drawn through the long axis of the lower central incisor.
Articulare-Sphenoethmoid-Pterygomaxillary Fissure (ARSE)	Angle formed by the junction of the Björk Articulare with the sphenoethmoid pterygomaxillary fissure vertical as illustrated by Enlow (1971) and van der Linden and Enlow (1972).

TABLE II

LINEAR MEASUREMENTS

Measurement	Definition
Overbite (OB)	Distance between the tip of the lower central incisor and the tip of the upper central incisor measured perpendicular to the functional occlusal plane.
Intermolar Distance (MWID)	Distance measured in tenths of a millimeter from the mesial buccal cusp tip of the lower right first molar to the mesial buccal cusp tip of the lower left first molar.
Intercuspid Distance (Cuspid)	Distance measured in tenths of a millimeter from the cuspid tips of the mandibular right and left canines.
Corpus Length Difference (Corpus)	Mandibular corpus length minus the length of the maxillary corpus to the nearest millimeter.
Alveolar Length Difference (Alven)	Mandibular alveolar bone length minus the length of the maxillary alveolar bone to the nearest millimeter.
Arch Length (Arch)	Distance from mesial anatomic contact point of the left mandibular first molar to the mesial contact points of the mandibular central incisors.
Incisor Irregularity (I)	The total of the distances between individual anatomical contact points of the mandibular incisors. There are 5 distances involved: left cuspid to left lateral, left lateral to left central, left central to right central, right central to right lateral, right lateral to right cuspid, as defined by Little (1975).

TABLE III

DESCRIPTIVE MEASUREMENT

Measurement	Definition
Curve of Spee (Curve)	The amount of curve deflection to a straight line from the incisal edge of the lower central incisors to the distal of the lower second molars. Three descriptive categories are utilized: flat, average and deep. Flat has less than 2 mm deflection, average is between 2 and 4 mm of deflection, and deep is greater than 4 mm of deflection.

Fig. 1. SNA, The angle formed by the intersection of the Sella-Nasion plane and a line connecting Nasion to A point.

SNB, The angle formed by the intersection of the Sella-Nasion plane and a line connecting Nasion and B point.

ANB, The angle formed by lines NA and NB at Nasion.

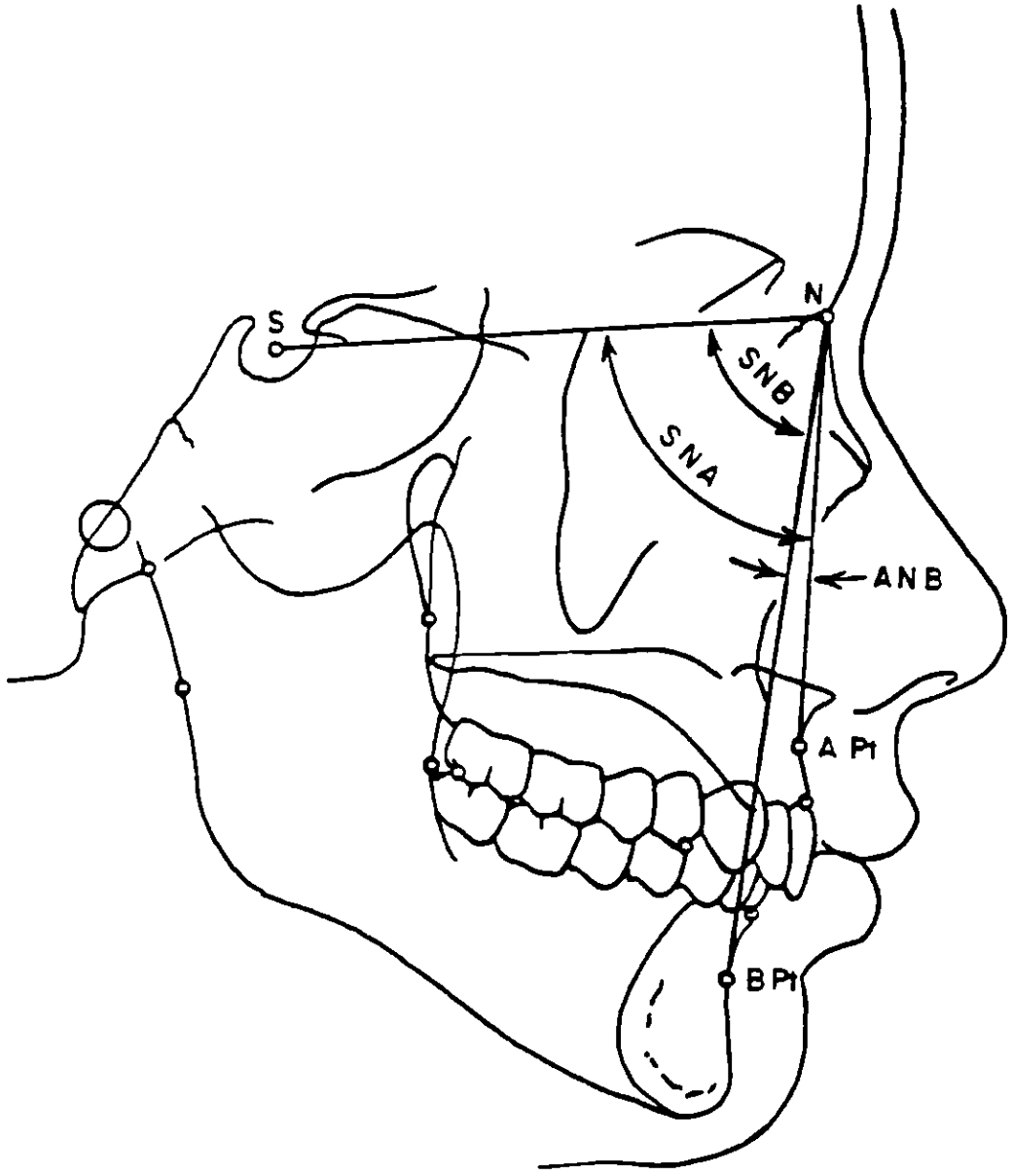


Figure 1

Fig. 2. FMA, The angle of the mandibular plane in relation to Frankfort horizontal.

IMPA, The angle of the mandibular plane in relation to a line drawn through the long axis of the lower central incisors.

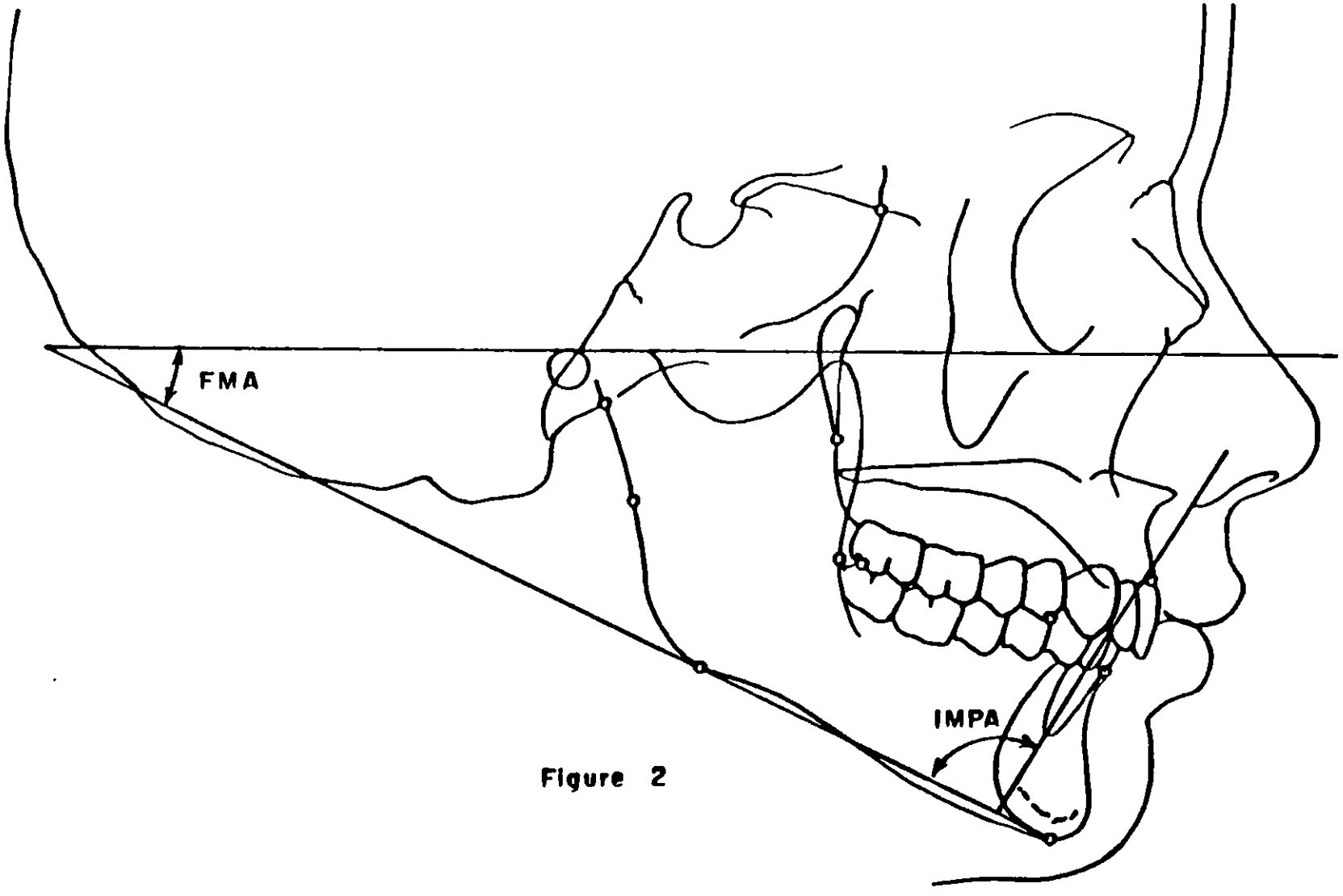


Figure 2

Fig. 3. SNFOP, The angle formed by the junction of Sella-Nasion and the functional occlusal plane.

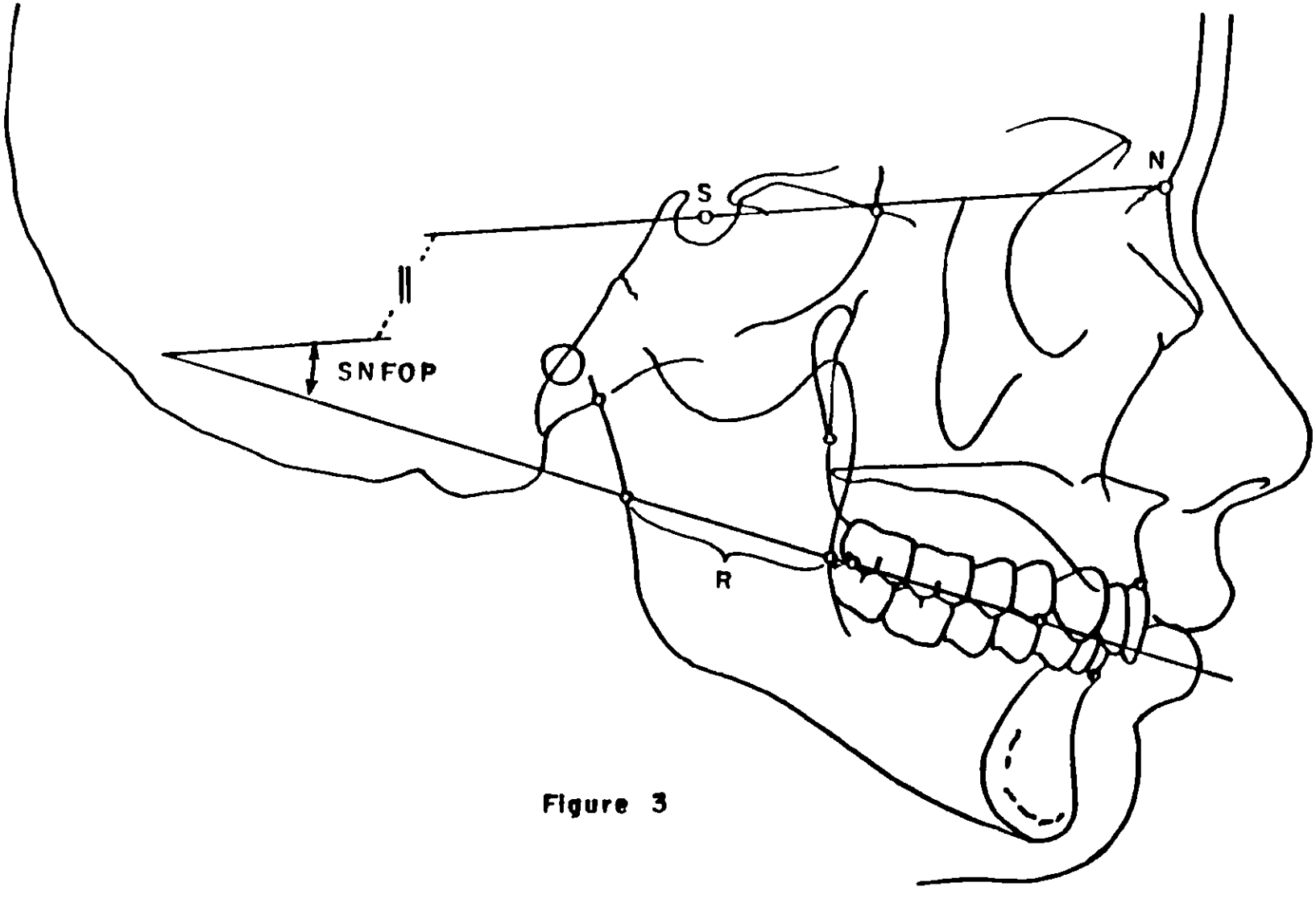


Figure 3

Fig. 4. AR-SE-PTM, The angle formed by the junction of the Björk Articulare with the sphenoethmoid pterygomaxillary fissure vertical.

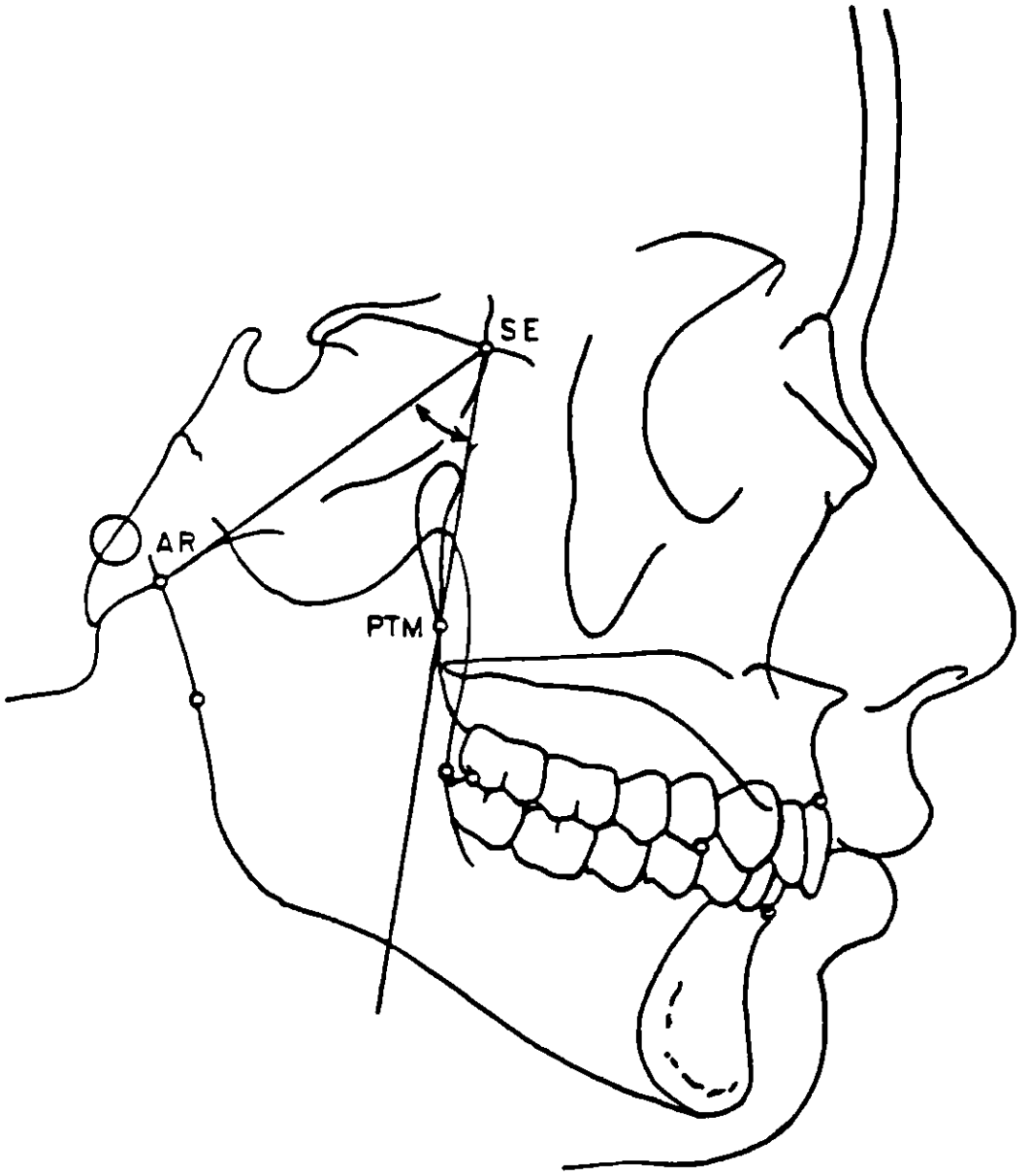


Figure 4

Fig. 5. Overbite, The distance between the tip of the lower central incisor and the tip of the upper central incisor measured perpendicular to the functional occlusal plane.

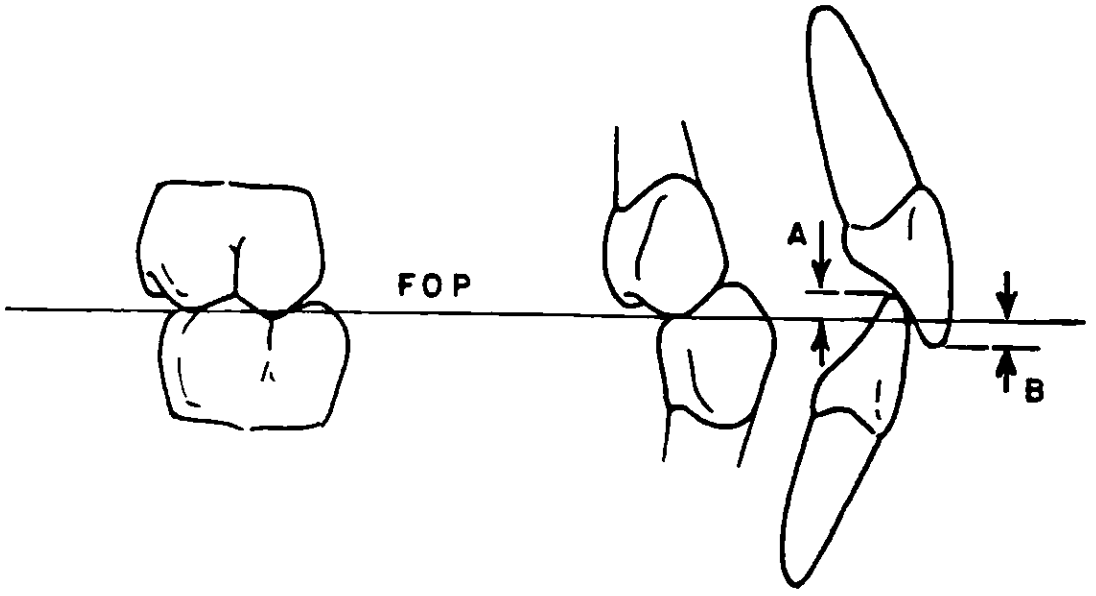


Figure 5

Fig. 6. Corpus Length Difference, The length of the mandibular corpus minus the length of the maxillary corpus. This is derived from the distance between the projection of the lingual tuberosity to the projection of B point minus the distance between the projection of PTM to the projection of A point.

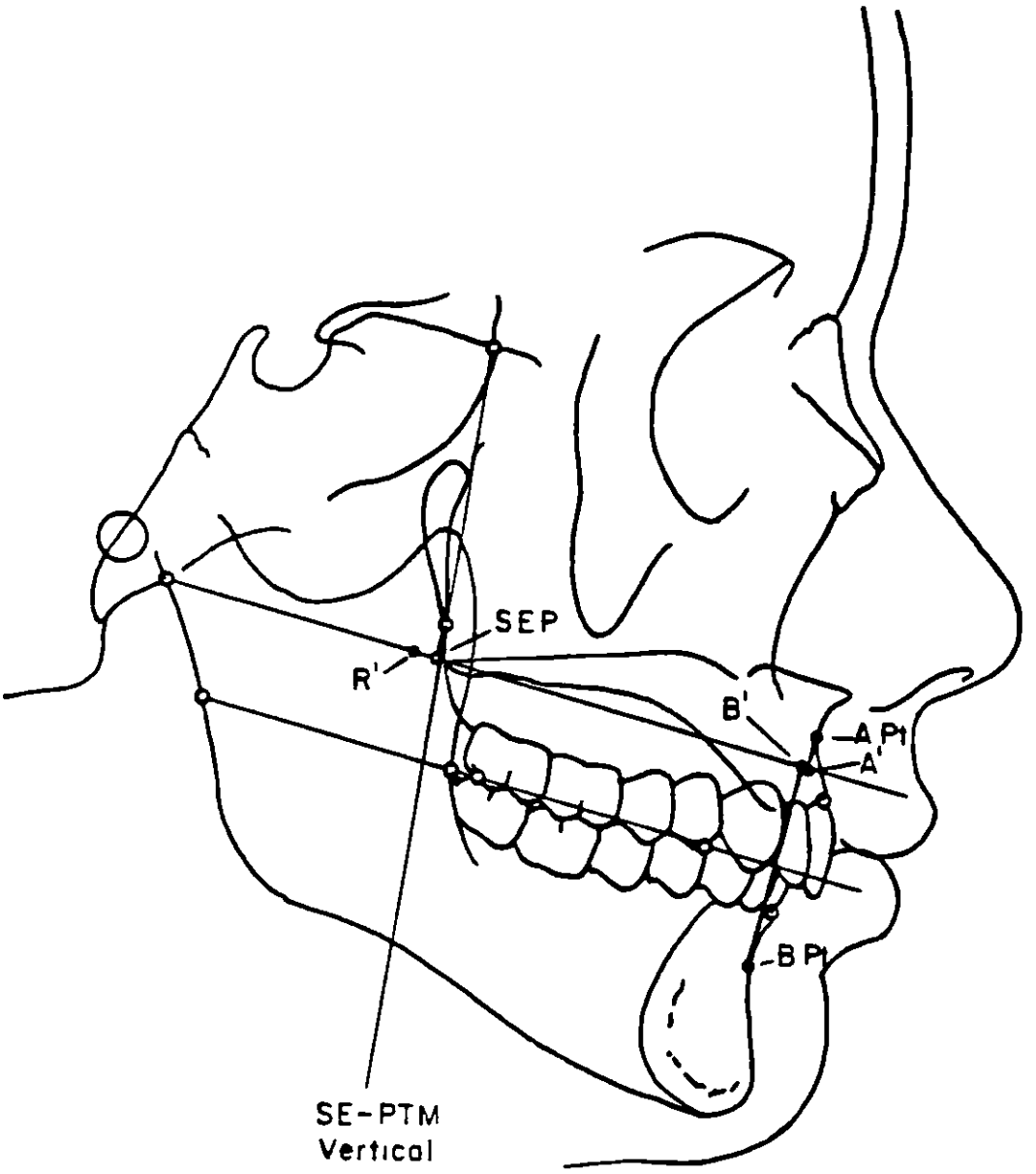


Figure 6

Fig. 7. Alveolar Length Difference, The length of the mandibular alveolar bone minus the length of the maxillary alveolar bone. This is derived from the distance between the projection of the lingual tuberosity to the projection of infradentale minus the distance between the projection of PTM to the projection of supradentale.

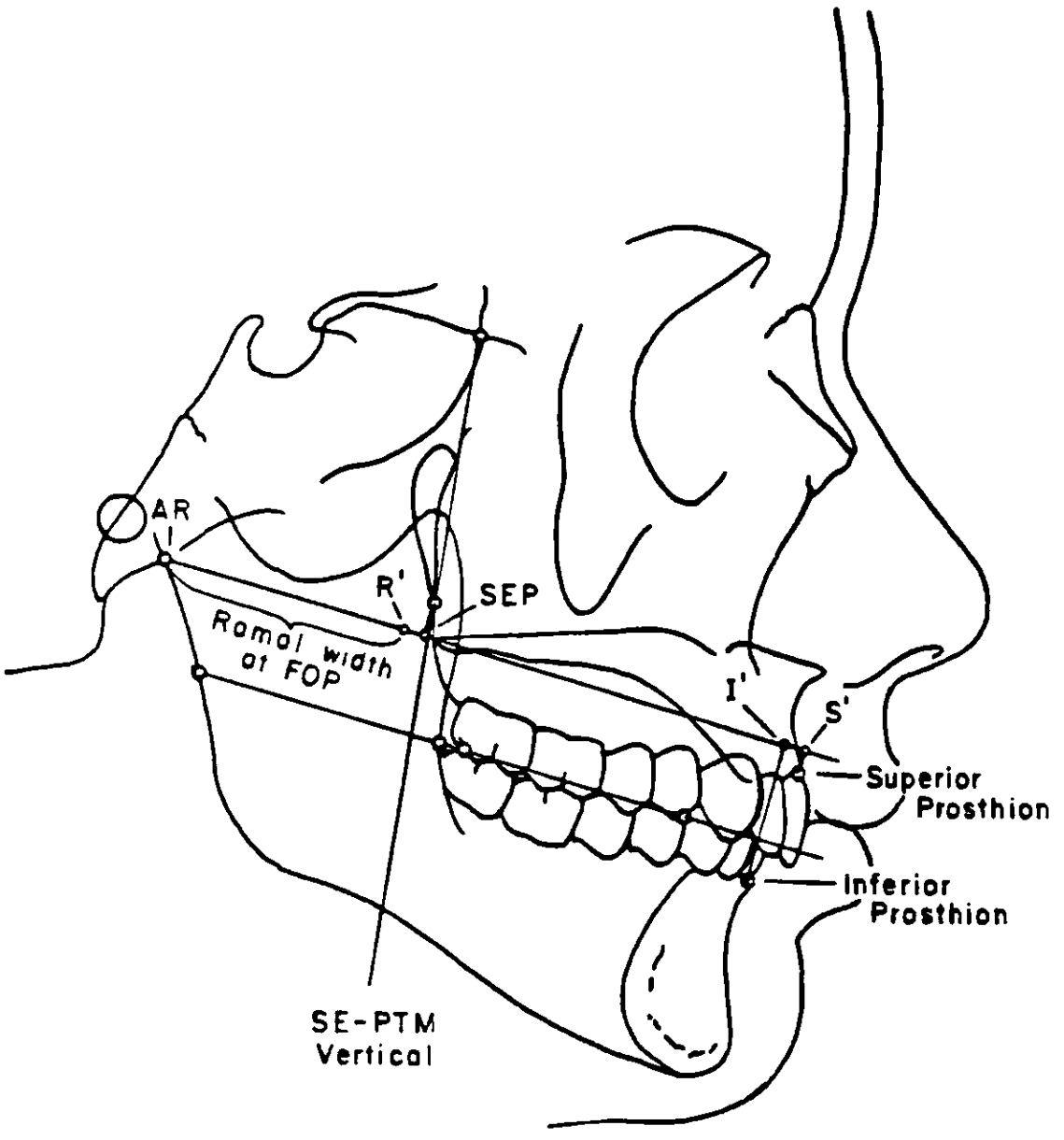

AR
R'
SEP
Romal width at FOP
I'
S'
Superior Prosthion
Inferior Prosthion
SE-PTM Vertical

Figure 7

Fig. 8. Intermolar Distance, molar width dimension, The distance between the mesial buccal cusp tip of the mandibular right first molar and the mesial buccal cusp tip of the mandibular left first molar.

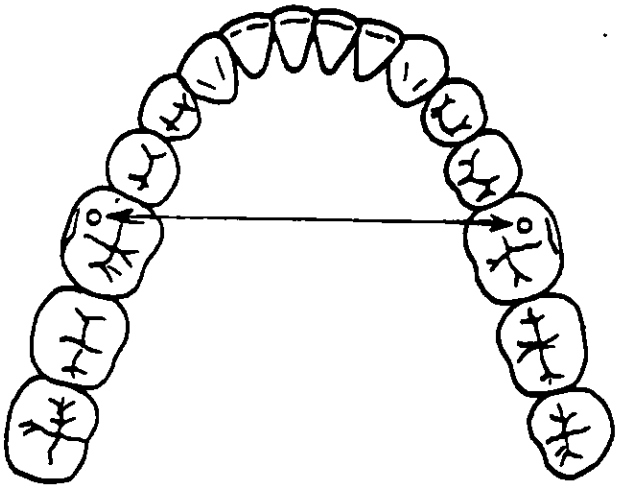


Figure 8

Fig. 9. Intercuspid Distance, Cuspid Width Dimension, The distance between the cusp tip of the mandibular right and left canines.

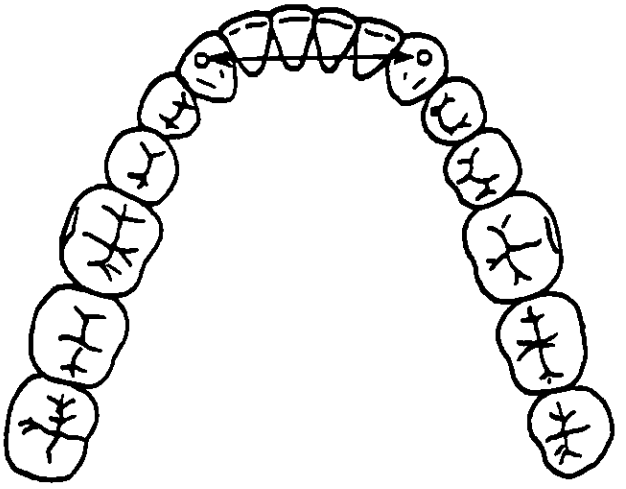


Figure 9

Fig. 10. Arch Length, The distance from the mesial anatomic contact point of the left mandibular first molar to the mesial contact point of the mandibular central incisors.

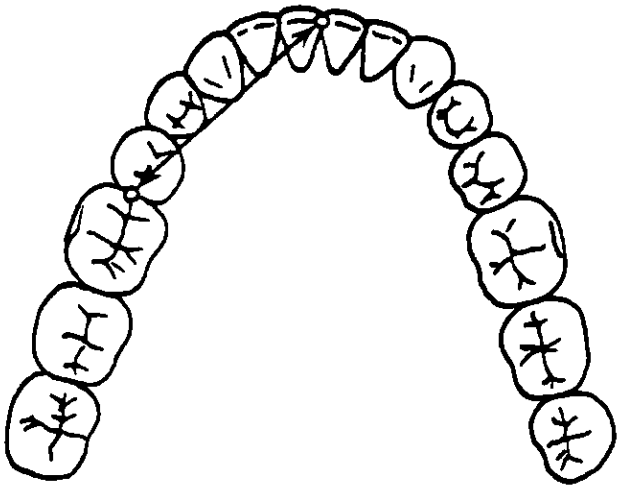


Figure 10

Fig. 11. Incisor Irregularity, The irregularity index was reworded as the sum of the distances between the anatomical contact points of the:

A. left cuspid and left lateral incisor
B. left lateral and left central incisors
C. left and right central incisors
D. right central and right lateral incisors
E. right lateral incisor and right cuspid

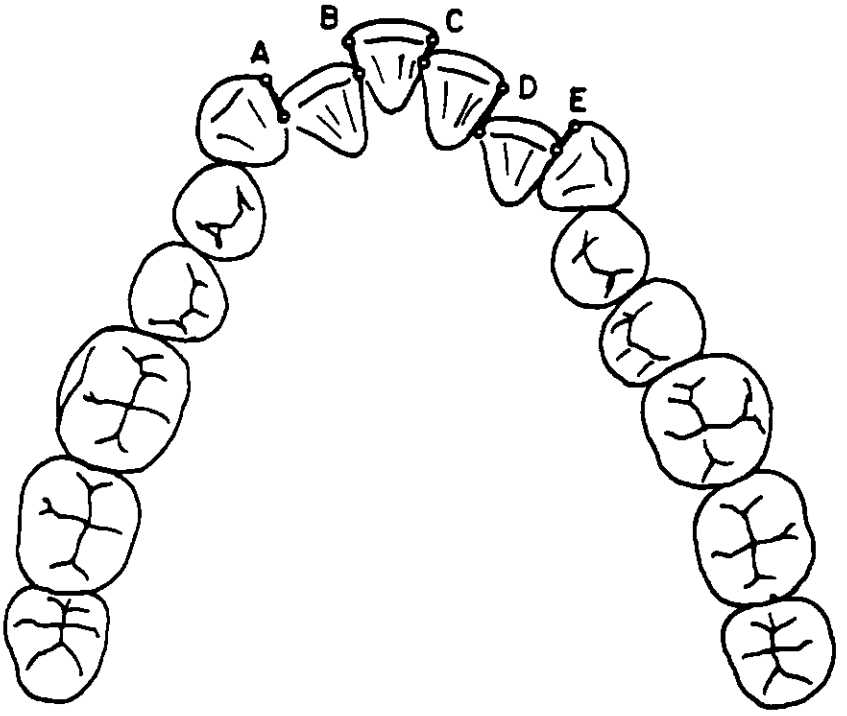


Figure 11

$$Y' = A + B_1X_1 + B_2X_2 + \ldots + B_kX_k$$

Where Y' represents the estimated value for Y, A is the Y intercept, and the B_1's are regression coefficients. Selection of the optimum A and B_1 coefficients using the least squares criterion also implies that the correlation between the actual Y values and the Y' estimated values is maximized.

6. Discriminant Analysis--Discriminant analysis begins with the desire to statistically distinguish between two or more groups of cases. Discriminant analysis attempts to do this by forming one or more linear combinations of the discriminating variables. These discriminant functions are of the form:

$$D_i = d_{ij}Z_1 + d_{i2}Z_2 + \ldots + d_{ip}Z_p$$

Where D_i is the score on the discriminant function i, the d's are weighting coefficients, and the Z's are the standardized values of the p discriminating variables used in the analysis. The functions are formed in such a way as to maximize the separation of the groups. Weighting coefficients can be interpreted much as in multiple regression or factor analysis. In this respect they seem to identify the variables which contribute mostly to differentiation along the respective dimension (function).

For the stepwise selection method, independent variables are selected for full entry into the analysis on the basis of their discriminating power.

LEGEND

Age = = Age of the individual

Curve = Curve of Spee

SNA = Angle SNA

SNB = Angle SNB

Corpus = Corpus length difference

Alven = Alveolar length difference

OB = Overbite

ARSE = Angle AR-SE-PTM

SNFOP = Angle SN-Functional Occlusal plane

IMPA = Angle IMPA

MWD = Molar width dimension

Cuspid = Cuspid width dimension

Arch = Arch length dimension

I = Incisor Irregularity Index

Angle = Molar classification, either Angle Class I or Class II

Sex = Sex of the individual

Var = Collection of the dependent variables of each observation depending on the respective subscript, i.e., Var_2, all the dependent variables at the final observation.

Subscript 1 = denotes the variable at the first observation, i.e., OB_1 is the amount of overbite present at the initial examination

Subscript 2 = denotes the variable at the second observation, i.e., OB_2 is the amount of overbite present at the final examination.

Subscript 3 = denotes the variable derived from the change in the

variable between the first and second observation, i.e., $OB_3 = OB_2 - OB_1$ which is the amount and direction of change that has occurred in overbite between the initial and final examination.

FINDINGS

Means and Standard Deviations

Means and standard deviations for variables at the initial and final observations and the change between the initial and final observations are presented in Tables IV, V and VI, respectively. Note that FMA and SNFOP decreased with time, as did cuspid width, molar width, overbite and arch length. On the other hand, SNA, SNB and incisor irregularity increased during this same time frame.

Incisor Irregularity, grouped by Angle classification (Class I and II) is presented in Table VII with its corresponding means and standard deviations. Crowding is observed at the initial examination (I_1), the final examination (I_2), or calculated as the change that has taken place between examinations (I_3). The Class II cases showed a higher net change in irregularity, whereas the Class I cases displayed more irregularity at both the initial and final observations. However, there was no statistically significant differences in crowding between Angle classification groups at the original or final observation or the differences between observations (Appendices 3-5).

Incisor Irregularity at each observation and the disparities between observations are exhibited in Table VIII as related to sex characteristics. The maximum and minimum values for males and females at all three reference points, initial crowding (I_1), final crowding (I_2) and change in crowding between observations (I_3), are also listed. Note that the females showed more crowding at the

TABLE IV

VARIABLES AT THE INITIAL OBSERVATION, MEANS AND STANDARD DEVIATIONS

Variable	Mean	S.D.
Age	12.21 years	.59
SNA	80.86 degrees	3.06
SNB	77.16 degrees	3.17
FMA	28.04 degrees	5.59
Corpus	2.26 mm.	2.88
Alven	-0.98 mm.	2.99
OB	4.96 mm.	1.46
ARSE	40.02 degrees	3.20
SNFOP	18.46 degrees	3.82
IMPA	96.56 degrees	8.26
MWID	42.80 mm.	3.67
Cuspid	25.70 mm.	3.44
Arch	30.59 mm.	2.83
I	3.70 mm.	2.29

TABLE V

VARIABLES AT THE FINAL OBSERVATION, MEANS AND STANDARD DEVIATIONS

Variable	Mean	S.D.
Age	18.80 years	1.61
SNA	81.82 degrees	3.20
SNB	78.92 degrees	3.48
FMA	25.96 degrees	5.93
Corpus	3.18 mm.	2.95
Alven	-0.60 mm.	3.01
OB	4.38 mm.	1.54
ARSE	39.48 degrees	3.18
SNFOP	16.78 degrees	4.04
IMPA	95.86 degrees	8.30
MWID	42.74 mm.	3.90
Cuspid	25.19 mm.	3.42
Arch	29.00 mm.	2.09
I	4.32 mm	2.64

TABLE VI

DIFFERENCE BETWEEN INITIAL
AND FINAL OBSERVATIONS
OF EACH VARIABLE

Variable	Mean	S.D.
Age	6.60 years	1.70
SNA	0.96 degrees	1.18
SNB	1.76 degrees	1.24
FMA	-2.08 degrees	2.72
Corpus	0.92 mm.	1.89
Alven	0.38 mm.	1.55
OB	-0.58 mm.	1.05
ARSE	-0.54 degrees	1.56
SNFOP	-1.68 degrees	2.31
IMPA	-0.70 degrees	2.46
MWID	-0.60 mm.	3.09
Cuspid	-0.51 mm.	0.96
Arch	-1.59 mm.	1.60
I	0.62 mm.	1.44

TABLE VII

INCISOR IRREGULARITY BY

ANGLE CLASSIFICATION

I	Angle	Mean (mm)	S.D.
I_1	Class I	4.25	2.71
	Class II	2.87	1.04
I_2	Class I	4.78	3.02
	Class II	3.64	1.77
I_3	Class I	0.53	1.64
	Class II	0.77	1.45

Composition of Sample

Angle Class I = 60%
Angle Class II = 40%
100%

TABLE VIII

INCISOR IRREGULARITY BY SEX

	I_1		I_2		I_3	
	Male	Female	Male	Female	Male	Female
Mean	3.36	4.16	4.05	4.70	0.68	0.54
S.D.	1.68	2.91	2.21	3.16	1.44	1.47
Max.	7.40	11.30	9.30	13.90	5.20	2.60
Min.	0.90	0.80	0.80	1.10	-2.50	-1.80

Composition of Sample

Males = 58%
Females = 42%
100%

initial and final observations, while males showed a greater net increase in irregularity. No statistically significant differences in relation to crowding were found between sexes at the original or final observation or the change between observations (Appendices 3-5).

The distribution of the net change in crowding (I_3) is presented in Table IX. The sample was divided into three groups for classification basis. The less-than-zero group represents those individuals who had a favorable change of crowding with time. This group will be referred to as the favorable crowding group. The middle group, represents those individuals who developed moderate crowding (0-1.25 mm) during the time period studied. This group appears to be very consistent with the pattern of skeletal, cephalometric and dental changes for that of the entire sample. The group where I_3 was greater than 1.25 mm and comprises the individuals who demonstrated incisor irregularity changes greater than 1.25 mm between observations. This group will be referred to as the severe crowding group. Listings of the favorable crowding group ($I_3<0$) and severe crowding group ($I_3>1.25$) with their original and final incisor irregularity indices are presented in Appendices 6 and 7.

Arch length is compared to incisor irregularity in Table X. The changes in the arch length dimension for the initial observation ($Arch_1$), the final observation ($Arch_2$) and the amount of arch length loss between observations ($Arch_3$) is recorded. The changes in arch length are compared for the favorable crowding group ($I_3<0$), the severe crowding group ($I_3>1.25$) and the entire sample (I_3 total).

TABLE IX

DISTRIBUTION OF THE CHANGE IN CROWDING (I_3)

	<0	0-1.25	>1.25	Total
N	16	18	16	50
%	32	36	32	100

TABLE X

COMPARISON OF THE ARCH LENGTH DIMENSION WITH THE FAVORABLE CROWDING GROUP (I_3<0), THE SEVERE CROWDING GROUP (I_3>1.25) AND THE ENTIRE SAMPLE (I_3 TOTAL)

	I_3<0		I_3>1.25		I_3 Total	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
$Arch_1$	30.40	2.65	30.33	2.07	30.59	2.83
$Arch_2$	28.81	2.61	29.13	1.76	29.00	2.09
$Arch_3$	-1.59	. .	-1.20	. .	-1.59	. .
N	16	. .	16	. .	50	. .

Note that the amount of arch length loss is similar in all three groups, with the severe crowding group exhibiting the smallest amount of arch length loss. The individual arch length changes for the favorable crowding and the severe crowding groups are listed in Appendices 8 and 9.

Means and standard deviations for molar width and cuspid width dimensions with their corresponding incisor irregularity values for the entire sample are listed in Table XI. The changes that have taken place (subscript 3) are included. Note that average cuspid width and molar width dimensions decreased by 0.5 mm and 0.6 mm, respectively, between ages 12 and 18 years, while the incisor irregularity index increased by 0.6 mm during the same time period.

Cuspid and molar width dimensions of the favorable crowding and severe crowding groups are compared with cuspid and molar width dimensions of the entire sample for the initial and final observations (Table XII). Cuspid width changes ($Cuspid_3$) and molar width changes ($MWID_3$) for the total sample are compared to those of the severe crowding ($I_3>1.25$) and favorable crowding groups ($I_3<0$). Note the striking similarities of the changes in cuspid dimension for all three groups. Listings for individual cuspid and molar width dimensions for the population with favorable crowding and severe crowding are given in Appendices 10 and 11.

The population showing favorable crowding changes ($I_3<0$) is listed in Table XIII, and those exhibiting severe crowding ($I_3>1.25$) are presented in Table XIV. Means and standard deviations for the incisor irregularity index at the initial and final observations are

TABLE XI

COMPARISON OF INCISOR IRREGULARITY WITH CUSPID AND MOLAR DIMENSION

Var.	Mean	S.D.	Max.	Min.
$Cuspid_1$	25.70	3.44	43.2	20.9
$MWID_1$	42.80	3.67	51.4	34.2
I_1	3.70	2.29	11.3	0.8
$Cuspid_2$	25.19	3.42	43.20	20.30
$MWID_2$	42.74	3.90	54.50	34.50
I_2	4.32	2.64	13.90	0.8
$Cuspid_3$	-0.51	0.96	1.73	-2.30
$MWID_3$	-0.60	3.09	12.00	-10.70
I_3	0.62	1.44	5.20	-2.50

TABLE XII

COMPARISON OF CUSPID WIDTH AND MOLAR WIDTH DIMENSION FOR THE FAVORABLE CROWDING GROUP ($I_3<0$), SEVERE CROWDING GROUP ($I_3>1.25$) AND THE ENTIRE SAMPLE (I_3 TOTAL)

	$I_3<0$		$I_3>1.25$		I_3 Total	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
$Cuspid_1$	26.06	5.41	25.19	2.37	25.70	3.44
$Cuspid_2$	25.65	5.24	24.63	2.80	25.19	3.42
$MWID_1$	42.73	4.31	43.41	3.60	42.80	3.67
$MWID_2$	41.92	4.83	43.63	3.98	42.74	3.90
$Cuspid_3$	-0.41	. .	-0.56	. .	-0.51	. .
$MWID_3$	-0.81	. .	+0.22	. .	-0.60	. .
N	16	. .	16	. .	50	. .

TABLE XIII

INCISOR IRREGULARITY IN THE POPULATION SHOWING FAVORABLE CROWDING CHANGES

(I_3<0)

	I_1 (mm)	I_2 (mm)	I_3 (mm)
Mean	4.40	3.42	-0.98
S.D.	2.32	2.39	0.56

Composition of Sample

Class II	= 38%	Males	= 56%
Class I	= 62%	Females	= 44%
	100%		100%

TABLE XIV

INCISOR IRREGULARITY IN THE POPULATION EXHIBITING SEVERE CROWDING CHANGES (I_3>1.25)

	I_1 (mm)	I_2 (mm)	I_3 (mm)
Mean	3.78	5.96	2.19
S.D.	2.65	2.99	0.99

Composition of Sample

Class II	= 44%	Males	= 44%
Class I	= 56%	Females	= 56%
	100%		100%

provided. The populations are further classified as to sex and molar classification composition. Interestingly, the favorable crowding group showed a greater average irregularity at the original observation than did the severe crowding group. However, the favorable group displayed an average natural correction of 1.0 mm, while the severe crowding group showed an average increase in irregularity of 2.2 mm.

Univariate Analysis of Variance

No single variable yielded a significant F value at either the initial or final observation, or the difference between initial and final observations. Therefore, these statistics were deleted from the Results section.

Pearson's Correlation Coefficients

This analysis provided statistically significant pairs of variables for $p<.05$, $p<.01$ and those variables for which there was a high degree of significance, $p<.001$. Table XV lists the significant pairs of variables at the initial observation ($Variables_1$), Table XVI lists those at the final observation ($Variables_2$), and Table XVII lists those determined from the differences between the initial and final observations ($Variables_3$). Also, combinations of mixed variables are included in Table XVIII. Note that the change in incisor irregularity (I_3) is not correlated to any variable determined from the differences between the initial and final observations. Furthermore, the only variable with which I_3 shows correlation

TABLE XV

PEARSON'S CORRELATION COEFFICIENTS FOR VARIABLES[1]

$\alpha = .05$	$\alpha = .01$	$\alpha = .001$
SNB (-) Curve	Curve (+) Angle	SNB (+) SNA
FMA (-) SNB	SNB (-) Angle	Alven (-) Angle
Corpus (-) Angle	Alven (-) Curve	Alven (+) Corpus
Alven (+) SNB	OB (+) Angle	SNFOP (-) SNA
OB (+) Curve	IMPA (-) Corpus	SNFOP (-) SNB
OB (-) FMA	Arch (+) ARSE	SNFOP (+) FMA
OB (-) Alven	Angle (+) IMPA	IMPA (-) FMA
ARSE (+) Angle	Cuspid (+) Molar	Arch (+) IMPA
ARSE (+) Curve	I (-) ARSE	
ARSE (+) OB	I (-) IMPA	
SNFOP (+) Curve	I (-) Arch	
IMPA (-) Alven		
IMPA (-) SNFOP		
Arch (+) SNA		
I (-) Angle		

TABLE XVI

PEARSON'S CORRELATION COEFFICIENTS FOR VARIABLES$_2$

α = .05	α = .01	α = .001
SNB (-) Angle	FMA (-) SNA	SNB (+) SNA
Corpus (+) SNB	Corpus (-) Angle	FMA (-) SNB
OB (-) FMA	OB (+) Angle	Alven (-) Angle
OB (-) Corpus	ARSE (+) Angle	Alven (+) Corpus
OB (-) Alven	IMPA (-) Alven	SNFOP (-) SNA
ARSE (+) OB	MWID (-) OB	SNFOP (-) SNB
IMPA (+) SNA	Arch (+) ARSE	SNFOP (+) FMA
IMPA (+) ARSE	Arch (-) SNFOP	IMPA (+) Angle
IMPA (-) SNFOP	Cuspid (+) MWID	IMPA (-) FMA
Cuspid (+) SNB	I (+) SNFOP	IMPA (-) Corpus
Cuspid (-) OB	I (-) IMPA	Arch (+) IMPA
Arch (+) Angle		Arch (+) MWID
I (+) FMA		
I (-) ARSE		
I (-) Arch		

TABLE XVII

PEARSON'S CORRELATION COEFFICIENTS FOR VARIABLES$_3$

$\alpha = .05$	$\alpha = .01$	$\alpha = .001$
FMA (-) SNA	FMA (-) SNB	SNB (+) SNA
Alven (-) FMA	ARSE (+) SNA	Alven (+) Corpus
ARSE (-) FMA	SNFOP (-) SNA	SNFOP (-) SNB
SNFOP (+) Corpus	IMPA (-) Corpus	
IMPA (-) Alven		
Arch (+) SNFOP		
Cuspid (+) MWID		
Arch (-) MWID		

TABLE XVIII

PEARSON'S CORRELATION COEFFICIENTS

FOR MIXED VARIABLES

$\alpha = .05$	$\alpha = .01$	$\alpha = .001$
I_3 (+) FMA_1		I_3 (+) I_1
		I_3 (+) I_2
		I_2 (+) I_1

is the initial FMA, and this is an extremely weak association.

Multiple Stepwise Regression

This analysis was used in an effort to determine which of the independent variables is actually accounting for the variance in the dependent variable (incisor irregularity). The variable of age was deleted in these tests since its effect would be deleterious to our result, i.e., there is no advantage to attributing the variability of age at or around 12 to incisor irregularity at 12. Table XIX illustrates initial incisor irregularity versus the variables at the initial observation. The total regression accounts for 44% of the variability, with IMPA being the major contributor at 13%.

Final incisor irregularity versus variables at the final observation accounts for only 30% of the variability, with IMPA again representing the greatest part at 11% (Table XX). For the net change in incisor irregularity (I_3) versus the changes in variables between observations (Table XXI), the percentage of regression drops to 21%, with IMPA being completely discounted as a contributing statistic.

The changes in incisor irregularity (I_3) versus the variables at the initial observation (including the original incisor irregularity) are given in Table XXII. With the regression accounting for merely 17% of the variability, 6 factors are noted as having some importance, the most notable being the original FMA with 6% of the variability. Moreover, initial incisor irregularity is not among the responsible factors. In other words, not even the most important

TABLE XIX

MULTIPLE STEPWISE REGRESSION

I_1 vs. VAR_1

Variable	R^2 Change
$IMPA_1$	.13988
$ARSE_1$	.08927
$Curve_1$	.12148
$MWID_1$	.05007
Angle	.04651

Total Linear Combinations

Multiple R .68874

R^2 .44721

TABLE XX

MULTIPLE STEPWISE REGRESSION

I_2 vs. VAR_2

Variable	R^2 Change
$IMPA_2$	.11057
$ARSE_2$	.05640
$SNFOP_2$	.05943
OB_2	.05569
$Curve_2$	.02052

Total Linear Combinations

Multiple R .55011

R^2 .30262

TABLE XXI

MULTIPLE STEPWISE REGRESSION

I_3 vs. VAR_3

Variable	R^2 Change
$Arch_3$	.03558
$ARSE_3$	.04196
$Cuspid_3$	.03918
$MWID_3$	.07029
FMA_3	.02311

Total Linear Combination

Multiple R .45838

R^2 .21012

TABLE XXII

MULTIPLE STEPWISE REGRESSION

I_3 vs. VAR_1 + I_1

Variable	R^2 Change
FMA_1	.06291
$Corpus_1$	.02062
$Alven_1$	.02603
$Curve_1$	.02561
OB_1	.01452
$IMPA_1$	.02191

Total Linear Combination

Multiple R .41425

R^2 .17160

factor in the group of six accounted for much of the variability, and the contribution of the entire group of six was not much more impressive.

The change in incisor irregularity (I_3) versus the variables at the initial observation (including original incisor irregularity) and the net change in variables between observations are presented in Table XXIII. Seven factors are observed yielding a regression which accounts for only 28% of the variability, and the original FMA is again responsible for the largest faction. Further, note that the original incisor irregularity is not a significant factor in this analysis.

Discriminant Function Analysis

A discriminant analysis was used in an effort to construct a linear combination of variables to account for incisor irregularity. Secondly, an attempt was made to derive linear combinations which would discriminate between the favorable crowding and severe crowding groupings. The final Wilks' Lamda (a measure of the amount of information left at the point of separation of groups), the canonical correlation, the discriminating variables along with their standardized coefficients, and the percentage of grouped cases correctly classified, are presented in the Discriminant Analysis section (Tables XXIV-XXVI). Notice some similarity between the discriminant analysis and multiple stepwise regression analysis pertaining to these factors.

TABLE XXIII

MULTIPLE STEPWISE REGRESSION

I_3 vs. VAR_1 AND VAR_3 + I_1

Variable	R^2 Change
FMA_1	.06291
$ARSE_3$	.04120
$MWID_3$	.03156
$Cuspid_3$	.05422
$Arch_3$	.04874
FMA_3	.02141
$Corpus_1$	.02650

Total Linear Combination	
Multiple R	.53529
R^2	.28654

The net change in crowding (I_3) versus the variables at the original observation is presented in Table XXIV. The groups were divided into cases which had favorable changes (<0) and cases in which the change was not favorable (>0). The overall predictability for group discrimination was almost 70%. Further, the unfavorable crowding group was then analyzed as to moderate ($0<I_3<1.25$) and severe crowding ($I_3>1.25$ mm). After a linear combination of discriminating variables was constructed these groupings were correctly predicted quite dramatically--better than 90% of the time (Table XXV). Note that neither the discriminating factors nor the equations for these two discriminant analyses are similar. Finally, in an attempt to analyze changes that had taken place between favorable and unfavorable crowding groupings a discriminant analysis was conducted on the change in irregularity (I_3) versus the original variables (VAR_1) and the net change in variables (VAR_3) (Table XXVI). In all, after the analysis had determined a linear combination of discriminating variables, greater than 70% of the cases were correctly classified.

TABLE XXIV

DISCRIMINANT ANALYSIS

I_3 vs. VAR_1

Group 1<0
Group 2>0

Variable	Standardized Coefficient
$Curve_1$	-0.85732
$Corpus_1$	1.29924
$Alven_1$	-1.12941
SNB_1	-0.33737
$IMPA_1$	0.30491

Canonical Correlation .434
Final Wilks' Lamda .8116

Actual Group	Number of Cases	Predicted Group Membership	
		Group 1	Group 2
Group 1	16	9(56.3%)	7(43.8%)
Group 2	34	9(26.5%)	25(73.5%)

Percent of "grouped" cases correctly classified: 68%

TABLE XXV

DISCRIMINANT ANALYSIS

I_3 vs. VAR_1

Group 1<1.25

Group 2>1.25

Variable	Standardized Coefficient
Sex_1	.55608
$MWID_1$	.92760
$Angle_1$	.98917
$Cuspid_1$	-.91272
SNB_1	.76113
FMA_1	.78726
$Arch_1$	.53314
$Alven_1$	.73601
$Corpus_1$	-.52016

Canonical Correlation .748

Final Wilks' Lamda .4404

Actual Group	Number of Cases	Predicted Group Membership	
		Group 1	Group 2
Group 1	18	17(94.4%)	1(5.6%)
Group 2	16	2(12.5%)	14(87.5%)

Percentage of "grouped" cases correctly classified: 91.2%

TABLE XXVI

DISCRIMINANT ANALYSIS

I_3 vs. VAR_1 AND VAR_3

Group 1<0
Group 2>0

Variable	Standardized Coefficient
$Curve_1$	-.69027
$MWID_3$	.45791
$SNFOP_1$	.44837
OB_3	-.45846
$ARSE_1$	.39120
SNB_3	.34112

Canonical Correlation .439
Final Wilks' Lamda .8071

Actual Group	Number of Cases	Predicted Group Membership	
		Group 1	Group 2
Group 1	16	11(68.8%)	5(31.3%)
Group 2	34	9(26.5%)	25(73.5%)

Percentage of "grouped" cases
Correctly Classified: 72%

DISCUSSION

The descriptive statistics and the analyses are presented in the section on Findings. Due to the large number of variables examined, however, it is difficult at first to distinguish the most pertinent and relevant findings. An attempt follows to interpret and explain in depth several important associations.

Angle Classification

A question first brought to mind when evaluating the conditions associated with incisor irregularity is whether or not there are differences related to Angle classification. In this study, 20 Class II, Division 1 cases and 30 Class I's were examined. Although a more balanced ratio of Class I to Class II's would be desired, the stringent requirements for selecting this study's sample made it difficult to find a larger number of Class II cases. Additionally, the lower rate of occurrence of Class II (as contrasted with Class I) malocclusions in the normal population as well as the desirability of seeking treatment for this malocclusion type accounts for the difficulty in readily locating a large untreated Class II sample. Over 3,000 cases were surveyed from the Bolton-Broadbent records before 20 acceptable untreated Class II cases were obtained (as outlined in Materials and Methods section).

Class I's displayed, at the 12 year old observation, an

average of 4.3 mm of crowding versus 2.9 mm for Class II's. At the 18 year old level, the average amount of crowding in the Class I cases (4.8 mm) still exceeded the value for the Class II's (3.6 mm), but the Class II cases showed a greater net increase in crowding between the 12 year and 18 year observations, 0.8 mm versus 0.5 mm for the Class I cases. Interestingly, the variability of incisor irregularity within the Class I cases was much higher than that for the Class II cases at both observations. A factorial analysis of variance showed that there were no statistically significant differences between Class I and Class II subjects with regard to incisor crowding at the original (I_1), final (I_2) or difference-between observations (I_3). Therefore, it can be stated that, although Class I cases experience somewhat more crowding, they could not be differentiated statistically from the combined population of Class I and Class II's on the basis of crowding alone. This finding justifies viewing this sample as one group of 50 rather than two sub-groups categorized by Angle classification.

Sex

The sample was grouped by gender into 29 males and 21 females. In regard to this study, the subjects were chosen at random so that inferences as to sex differences in incisor crowding are justified. When Fastlicht (1970) evaluated an untreated Michigan sample of 12 males and 16 females, he showed that males generally had a higher degree of crowding than females. In contrast, exactly opposite results were obtained by Lavelle (1969) who found

that females in his cross-sectional study displayed more crowding than did males. By virtue of his much larger sample size (N = 164 male, 164 female) . Lavelle's study is at least statistically more credible than Fastlicht's. It is important to note, however, that, unlike the current investigation, both of these studies evaluated crowding as a static phenomenon (i.e., at only one point in time) and did not evaluate at all the changes in crowding as the subjects aged. Nonetheless, it is interesting that the current study, with a sample nearly twice the size of Fastlicht's, seems to corroborate Lavelle's observation of greater crowding in females (as noted in Table VIII).

To expand on the present findings, females had a higher mean incisor irregularity at (I_1), the original observation, 4.2 mm as compared to 3.4 mm for the males. At the final observation, females once again showed a higher tendency towards crowding, 4.7 mm as compared to 4.0 mm for the males. Moreover, the group showing the greatest variability at these observations were females. An interesting contrast is that while female dentitions were, on the average, consistently more crowded throughout the observational ages, male dentitions showed a greater net increase in irregularity between observations (I_3)--possibly due to the slower, but more prolonged male growth span. However, a factorial analysis of variance to evaluate incisor irregularity on the basis of sex, showed no significant differences between sexes at the I_1, I_2 or I_3 levels. Therefore, while females have shown more crowding clinically at both observations, there is no meaningful statistical

differences between sexes.

Arch Length

A number of investigators have noted a decrease in arch length (Brown and Daugaard-Jensen, 1951; Barrow and White, 1952; Moorrees, 1959; Sillman, 1964; DeKoch, 1972), while some of these same observers and others have clinically observed increases in incisor irregularity (Barrow and White, 1952; Moorrees, 1959; Lundstrom, 1968; DeKoch, 1972). Therefore, "common sense" reasoning suggests that in some way these two factors must be inversely related i.e., cases showing a large decrease in arch length would be expected to show a great increase in incisor irregularity while cases where arch length is minimal would be expected to show considerable stability in incisor alignment.

Arch length was examined from a point in the late transitional dentition (12 year old reading) to a point in the adult dentition. The mean length at the initial observation was 30.59 mm, and decreased to 29.0 mm at the final reading. The net change over this 6 year-plus period was an average of 1.6 mm of arch length loss per quadrant which corroborates the findings of earlier investigators. Incisor irregularity was found on the average to increase (0.6 mm) with age; however, significant individual variations were observed ranging from 5.2 mm of severe change to 2.5 mm of natural net correction.

In the present study, a highly significant inverse correlation existed between arch length and the incisor irregularity at the

original observation ($p<.01$). At the final observation, arch length again was inversely correlated to irregularity ($p<.05$). Finally, when viewing the most revealing interaction--the change in arch length versus the change in crowding--no correlation as to the magnitude and direction of the changes of these variables was noted to be significant. Comparing these same variables in a multiple stepwise regression analysis, the regression of the change in arch length was found to account for only 3.5% of the variability. Thus, while the changes in arch length cannot be considered a completely insignificant factor in crowding, it is clearly not nearly as important as other factors such as cuspid width, molar width dimension changes and AR-SE-PTM changes (Table XXI).

When the net change in crowding was compared to the original variables and to the net change between variables (Table XXIII), arch length loss was observed to have a minimal contribution. Noticing that at least 6 other important factors exist that are involved in this process, proper perspective suggests that arch length loss may not be the over-riding factor responsible for crowding, but rather only one part of a composite multifactorial chain of reactions resulting in irregularity.

Finally, arch length dimensions at the 12 year and 18 year readings were compared for the entire sample and also for the favorable and severe crowding groups (Table X). In addition, the net change in arch length ($Arch_3$) for all three groups was computed. In the favorable crowding group (which maintained or improved upon its irregularity), arch length loss was found to be identical with

that of the entire sample. However, in the severe crowding group (where a greater than average amount of arch length loss would be expected to account for an increase in irregularity), the average arch length loss was 1.2 mm--or 0.4 mm less than that of the entire sample. Further, note that cases #141, 259, 3481, all showed an arch length loss of less than 0.3 mm, but nonetheless recorded severe changes in crowding (Appendix 9). Moreover, cases #2357, 2418 and 3232 exhibited tremendous arch length losses, yet recorded a net natural correction of irregularity (Appendix 8).

In view of the current findings, the overly simplistic presumption that decreased arch length leads to crowding finds no support. An alternate theory is therefore proposed that arch length is but one factor of a multidependent relationship which is associated with crowding and, consequently the influence of arch length change is subject to varying expression because of changed conditions in the individual's anatomical and skeletal architecture. It is, therefore, concluded that arch length decrease as it relates to the apical base theory does <u>not</u> represent the simple biological basis for crowding. To say the very least, in view of the current findings the presumed unifactorial cause and effect relationship between arch length loss and irregularity no longer seems tenable.

<u>Cuspid and Molar Width</u>

An often repeated clinical "rule of thumb" states that intercuspid and intermolar width changes are important factors in

explaining the process of crowding. The rationale behind this premise is that decreased molar and cuspid widths must, of course, result in less space for incisor accomodation. (Additionally, the mandibular incisors are regulated and manipulated by the upper incisors through function and occlusion, as well as by all of the interrelated growth changes occurring during the same time span.) Seemingly, the only possible physiologic response is for the lower incisors to crowd in order to achieve an equilibrium. Expanding upon this presumption, cases which maintain their intermolar and intercuspid dimensions would be expected to show the greatest stability, as both Strang (1952) and McCauley (1944) have both pointed out. On the other hand, cases showing the greatest decreases in these arch parameters would be expected to exhibit a high degree of crowding.

Gallerano (1976), based upon an examination of a treated sample, felt that the relapse (irregularity) seen on post-treatment and post-retention cases was independent of molar and cuspid dimension changes. However, his study lacked an untreated control group with which to compare the treatment effects and he was thereby unable to propose a definitive conclusion.

Over the duration studied presently, cuspid width was noted to decrease an average of 0.5 mm while the molar width decreased by 0.6 mm (Table X). These findings are hardly unexpected considering that almost every previous study has reported similar observations (Brown and Daugaard-Jensen, 1951; Barrow and White, 1952;

Sillman, 1964; Shapiro, 1974; Reidel, 1975; Gallerano, 1976). Concomitant with the decreased molar and cuspid widths the corresponding average incisor irregularity increased by 0.6 mm during this same period.

Incisor irregularity for the present sample was then selectively grouped according to cases showing favorable changes ($I_3<0$) and cases showing a high degree of crowding ($I_3>1.25$). Cuspid width and molar width dimensions for each of these samples, along with the change in these arch width dimensions, were calculated (Table XII). The favorable group showed a net natural correction of irregularity of 1.0 mm (Table XIII), while the crowded group displayed a net increase in irregularity of 2.2 mm (Table XIV). The average difference between the severe crowding and the favorable crowding groups in increase of crowding amounted to an average range of 3.2 mm of incisor displacement (i.e., the range between -2.2 mm and +1.0 mm, respectively). For the cases presenting favorable change in irregularity the cuspid width decreased by 0.4 mm, and the molar width decreased by 0.8 mm. While the average cuspid width of the favorable group decreased only 0.1 mm less than that of the entire sample (0.5 mm), the molar width of this same group decreased 0.2 mm more than the total sample. This finding is somewhat difficult to explain if the apical base theory is correct. Furthermore, the cases that exhibited a high degree of crowding actually showed an intercanine width decrease of 0.6 mm and an intermolar increase of 0.2 mm. Thus, there was virtually no

difference in the intercanine dimension decrease of the favorable group as compared to the crowding group, or to the entire sample.

It seems almost inconceivable that the small difference in the decrease of intercuspid width between the entire sample and the high crowding group (0.05 mm) could account for the widely differing amounts of crowding that were observed. Moreover, to regard the small differences between the intercuspid dimension changes of the severe and favorable crowding groups (0.15 mm) as being responsible for the wide disparities in their irregularities (3.2 mm) is untenable. Yet another finding contrary to the premise that arch width decreases lead to crowding is that the favorable crowding group exhibited a decrease of 0.8 mm in intermolar width while the severe crowding group presented a natural increase of the molar dimension of 0.2 mm.

It appears that the current findings deny a direct relationship between arch width changes and incisor irregularity increases. If cuspid and molar dimension changes are solely responsible for crowding responses, a logical explanation should be apparent in the data obtained. However, the results indicate that incisor crowding is the end product of a multifactorial group of conditions of which cuspid and molar dimension might not be paramount. More specifically, the findings of this study indicate that incisor irregularity and its changes are independent of the univariate parameters of arch width dimensions and their alterations.

Overbite

Contrary to studies in which overbite was measured either on plaster casts or directly from the individual patient, overbite in this study was measured cephalometrically relative to the functional occlusal plane. Regardless of the method for obtaining these measurements, the relative change should be comparable. At the initial observation overbite was found to be an average of 5.0 mm and at the final observation the value was 4.4 mm. The variability at either of these observations was extremely small. The amount of change in overbite between observations accounted for a net decrease of 0.6 mm. This finding complements that of Björk (1953) and others who found that overbite decreases with age in untreated individuals. Further, as Björk demonstrated, overbite is extremely stable. Overbite was observed to be directly correlated with Angle classification at the initial and final observations ($p<.01$). Thus, a greater tendency for overbite is exhibited at both observations with Class II molar relationships, while Class I malocclusions are associated with a lesser degree of overbite. The most revealing finding concerning overbite was a lack of correlation between crowding and overbite in untreated individuals.

Changes in Incisor Irregularity

Angle, in the early 1900's, proposed that malocclusions are stable. He and others believed that crowding would either stay the same or get worse. Numerous other studies have asserted that incisor

teeth became more irregular with increasing age (Grieve, 1944; Brown and Daugaard-Jensen, 1951; Brodie, 1953, 1954; Moorrees, 1959; Berger, 1959; Lavelle, 1968; Lundstrom, 1968; Fastlicht, 1970; De-Koch, 1972).

In the present study irregularity increased an average of 0.6 mm between the 12 year and 18 year old observation. Despite large individual variations incisor irregularity was rather stable in the sample studied (see Appendix 12). The findings of this study are in accord with those of the earlier investigators of crowding.

Only about one-third of the cases actually increased in crowding more than 1.25 mm (severe crowding), with one individual exhibiting an increase of 5.2 mm. On the other hand, almost one-third of the cases showed a net decrease (i.e., favorable crowding) in irregularity ($I_3<0$) between observations. A natural improvement in incisor alignment was an unexpected finding; yet, there were as many cases (untreated) which corrected themselves as those which showed crowding increases of more than 1.25 mm (16). There are presently no other studies to either support or refute this finding.

Sex did not appear to be a distinguishing factor in the group of cases exhibiting favorable changes ($I_3<0$). However, in the severe crowding group ($I_3>1.25$ mm) a predominance of females was found (56%). Therefore, although there are no great differences in these groups, females show a greater propensity for severe crowding than males. Angle classification by itself did not appear to be related to favorable or unfavorable irregularity changes with increasing age. Thirty-eight percent of the population of the

favorable crowding group were Angle Class II, while 44% of the population of the severe crowding group (I_3>1.25) were Class II malocclusions.

The theory advocated by Begg (1978) regarding the interaction of arch length loss and tooth attrition might possibly lend some insight as to the possible causes of the severe crowding and favorable crowding changes. Favorable crowding changes might be explained by a harmonious coordination of arch length loss, tooth attrition, and concomitant mesial drift whereas the severe crowding groups may have suffered from an alteration of the balance between these factors. It must be emphasized, however, that since mesiodistal widths were not measured in this study, no firm conclusion as to the validity of this theory can be drawn.

If no single factor such as age, arch width or length changes, or sex adequately explains incisor irregularity, then perhaps a different approach which merits examination is the hypothesis that crowding of the lower incisors is a natural adaptive mechanism which is continually being manipulated by the factors associated with growth and development (Highley, 1967). Earlier workers such as Brodie (1953, 1954), Berger (1959), Jarabak and Fizzel (1965) have all suggested that this is a workable hypothesis. Importantly, in the present study the net change in crowding (I_3) was not correlated significantly to any single variable of the first observation, the second observation, or differences between observations (Tables XV-XVIII). Therefore, since there are no significant correlations, only a combination of variables may account for the

change in irregularity. Further supporting this conclusion is the very small percentage of variability that is accounted for by the regression in the multiple regression analyses (Tables XIX-XXIII). While FMA is the largest contributor accounting for between 6-7% of the variability, no one factor can be singled out as being significantly more influencial than another in the overall process of incisor crowding changes.

Limitations

In this study, the effect of the erupting third molars was disregarded in relation to crowding. Many authors have studied third molar eruption and concluded that the eruption of these teeth has little significance in relation to incisor irregularity (Fastlicht, 1970; Shanley, 1962; Bergenstrom and Jensen, 1960). Nance (1947), recognized that, while most orthodontists have accepted the "common sense" explanation that the forward pressure of third molars is responsible for relapse of the lower incisors, in reality the third molars are merely "innocent bystanders" which erupt coincidently with the period during which relapse of treated cases is observed. He stated:

> If the precaution of removing third molars were always rewarded by a stable result, forward pressure of these teeth might satisfactorily explain relapses. But is it common knowledge that relapses of treated cases frequently occur after the removal of third molars and even in cases where they are congenitally absent.

Another possible limitation of this study is that the two methods for cast measurement in this study might be misleading.

Perhaps measurements from the labial aspects of the canine and molar teeth rather from the cusp tips might prove more accurate in analyzing expansion and constriction because the dimensional effect of torquing of the teeth (wherein certain portions of the tooth move more than others) would be minimized. Neither did this thesis examine muscle activity, habits, lip or tongue function. It is entirely possible that these factors may have an effect on irregularity.

Mesial and distal widths of incisor teeth were not measured in this study. The inclusion of the mesiodistal widths of the maxillary and mandibular anterior teeth might serve as a useful variable in a future study. Also, a productive determinant might be the incorporation of transverse dimensions from frontal headfilms. While the anatomical direction of research in this study was biased towards a lateral projection, the dentition is obviously housed in a three-dimensional skeletal and muscular matrix with growth occurring in a transverse vector as well as vertically and anteroposteriorly.

Sample and Examiner Bias

The study was not performed "double blind"; i.e., the examiner was familiar with the hypothesis. However, the examiner was biased to expect that malocclusions will become more irregular with time. Thus, if the experiment were to be repeated by an unbiased examiner, it is possible that a greater percentage of cases would be observed to change favorably and possibly the predictability of

the discriminating groups could be increased.

Limitations of the Irregularity Index

The irregularity index does not quantify vertical contact malpositions, rotations or spacing. This index deals strictly with the anteroposterior relationship of the incisor teeth without regard for malpositions, crowdings, spacings or rotations in the buccal segments. The measurement error was 0.27 mm and the 95% confidence interval of measurement error was ± 0.15 mm.

Predictability of Irregularity

One of the foremost dilemmas puzzling the dental profession is the ability to predict which cases will crowd as a result of growth and development. Prior to the present study, the possibility of a natural correction of irregularity was never considered reasonable. Now an even more perplexing situation occurs: can a natural correction, which heretofore was unrecognized, be predicted, and if so how successfully?

As previously reported herein, 16 cases were observed to demonstrate a natural correction (favorable crowding group) between the 12 year and 18 year observation. The corrected cases, Group 1 (favorable crowding) were tested against the cases which demonstrated crowding, Group 2, by a discriminant function analysis to see if either of the two groups had its own unique and characteristic set of variables by which it could be recognized. It was found that

the net change in crowding is linearly related to the change in molar width, overbite and SNB, as well as a combination of associated 12 year old variables (Tables XXI, XXIII and XXVI). In regard to the change in irregularity, there are strong similarities between the multiple regression and discriminant function analyses (Tables XXI-XXVI). However, there exists an array of factors which is indiginous to each analysis. This finding supports the theory that there exists a group of interdependent factors that are associated with the changes in irregularity.

In order to predict crowding, the 12 year variables were tested by a discriminant analysis against the change in crowding. The sample was divided into the 16 cases which exhibited a natural net correction of crowding (Group 1), and the 34 cases which exhibited a natural net increase in crowding (Group 2, Table XXIV). A linear combination of variables was calculated for both groups. When all 50 cases were compared using this linear combination, the grouped cases were correctly classified almost 70% of the time. In other words, an equation utilizing a combination of 5 variables (Curve of Spee, corpus length, alveolar length, SNB and IMPA measured at the 12-year observation) correctly predicted the direction of crowding that will develop at 18 years of age 70% of the time. Zero crowding change was initially selected arbitrarily as a natural separation point to differentiate the crowding-improved and crowding-worsened groups, but since the measurement error was approximately 0.3 mm, it was felt that a regrouping using 0.3 mm as the separation

point might generate a more competent discrimination. Group 1 was divided into cases where I_3<0.3 mm and Group 2 was divided into cases where I_3>0.3 mm. When a new linear combination of variables was determined with 0.3 mm as the separation point, the two groups were correctly classified almost 75% of the time. Noteworthy is the observation that the original incisor irregularity and the relation between the maxillary and mandibular apical bases (ANB) is not a contributing factor in either analysis. The standardized equation for the discriminating groups, D, with zero as the dividing point is:

$$D = - 0.85832\ (Curve_1) + 1.29924\ (Corpus_1) - 1.1294\ (Alven_1) - 0.33737\ (SNB_1) + 0.30491\ (IMPA_1).$$

The standardized coefficient (i.e., the number preceding each variable in the equation) relates the relative importance of each discriminating variable in the analysis to another discriminating variable. The larger the value of a positive coefficient the greater is the direct importance of that factor. A large negative value would indicate a sizable inverse effect. In the preceding equation, regarding the discrimination between favorable and unfavorable changes in crowding, corpus length would have the largest direct effect. Alveolar length would have the largest inverse effect and the contribution by IMPA is the least significant of the 5 contributing factors.

The discriminant function analysis was then employed to determine the predictability of cases showing unfavorable crowding.

Three groups were established: (1) favorable crowding (<0 mm), (2) moderate crowding (0-1.5 mm) and (3) severe crowding (>1.5 mm). The severe crowding group was found to be correctly classified to a level of greater than 90%; the discrimination between the other two groups was not as distinct. It was then reasoned that if the factors associated with a decrease in crowding were morphologically different from those relating to an increase in crowding, a better discrimination between groups could possibly be determined by deleting the favorable group and its corresponding information. This, in fact, turned out to be valid reasoning. The change in crowding was measured against two groups, Group 1 where $0<I_3<1.25$ mm (the range will be 0-1.25 mm since the less-than-zero group has been deleted) and the severe crowding group, Group 2 where $I_3>1.25$ mm (Table XXV). In all, the discriminant function went through 9 steps to obtain an equation. The canonical correlation is a measure of the function's ability to discriminate among groups. The larger the canonical correlation becomes, the greater is the function's ability to separate between groups. In this case, the canonical correlation was exceptionally high indicating an extremely good separation of groups. The linear combination of the 12 year variables correctly predicted the change in crowding occurring at 18 into moderate and severe crowding groups better than 90% of the time. In fact, only one case in 18 of the group which was predicted to crowd less than 1.25 mm was actually classified incorrectly, and of the 16 which exhibited severe crowding only 2 cases were misclassified. The actual standardized

equation for the discriminating groups, D, with 1.25 mm as the separation point is:

$$D = 0.55608\ (Sex_1) + 0.92769\ (MWID_1) + 0.98917\ (Angle_1) - 0.91272\ (Cuspid_1) + 0.76113\ (SNB_1) + 0.78726\ (FMA_1) + 0.53314\ (Arch_1) + 0.723601\ (Alven_1) - 0.52016\ (Corpus_1).$$

In the process of testing for assorted combinations of significant variables, it was actually found that when original ANB and original incisor irregularity were deleted from the list of variables, group discrimination improved as did the percent of cases correctly classified. Therefore, it is important to recognize that the crowding that occurs at 18 can be correctly predicted an extremely high percentage of the time, but the prediction is completely independent of ANB and, more importantly, completely independent of the irregularity which is observed at the original observation.

Upon comparing the discriminant analysis for separating favorable and unfavorable crowding to that for separating severe and moderate crowding, it becomes apparent that the discriminating factors for the two equations are significantly different. Only 3 of the 5 factors from the favorable-unfavorable (improved-worsened) analysis are repeated in the 9 factors severe-moderate analysis (SNB, Corpus, Alven). This, in fact, would tend to indicate that the factors responsible for a natural net correction of irregularity <u>are not</u> necessarily the same factors responsible for severe crowding. Moreover, in the favorable-unfavorable analysis all the discriminating factors with the

exception of Curve of Spee are anatomic or cephalometric variables as compared to only 4 of the 9 discriminating factors in the severe-moderate analysis. Consequently, the disparity in equations of the discriminant analysis would indicate that the predisposing factors associated with a correction of crowding are more closely related to anatomic and cephalometric variables, while the factors associated with an increase in irregularity are more closely associated with the combination of anatomical, cephalometric and dental variables.

Thus, after isolating the groups exhibiting favorable, moderate and severe changes in crowding, no predominant causal factor can be recognized. It becomes evident, through the statistical and mathematical inferences in this study that many of the assumed truths and generally accepted dogmas are scientifically unfounded. Rather, a highly complex and intricate interaction of numerous craniofacial and dental matrices are involved as factors predisposing to crowding during the normal growth process.

SUMMARY AND CONCLUSIONS

Despite long standing interest in the subject of incisor crowding, no comprehensive understanding of the quantitative changes in incisor alignment during normal growth and development in the untreated population exists. Accordingly, the purpose of this study is to identify and quantify those changes in incisor crowding that takes place in the mandibular dental arches of untreated individuals. These changes are evaluated from measurements of dental casts and lateral headfilms of 50 individuals at ages corresponding to pretreatment and at least 3 years post-retention. Incisor Irregularity is quantatatively measured at each observation and related to specific anatomic and cephalometric conditions in the face and dental arches. Study model parameters as well as anatomic and cephalometric variables at both the initial and final observations are evaluated for their relationship to crowding. Additionally, sex, age and Angle classification are evaluated for their contribution to crowding. A series of statistical tests (Pearson's Correlation Coefficients, Multiple Stepwise Regression and Discriminant Analyses) were employed to accurately analyze the interaction of these variables. Finally by analyzing variables from the 12 year old observation with a Discriminant Function Analysis, linear combinations of discriminating factors were constructed to predict the direction and the severity of crowding that occurred at 18 years of age.

The findings of this investigation suggest the following conclusions:

(1) No statistically significant relationship exists between incisor crowding and gender or Angle classification.

(2) Arch length, cuspid width and molar width changes were found to be insignificant factors in controlling crowding, but may contribute in small measure to a multi-dependent relationship which is associated with crowding.

(3) Incisor irregularity of the whole sample tended to increase with time, but nearly a third of the cases actually showed improvement in incisor alignment.

(4) No single variable measured at either observation time, or the change in any single variable between observations correlate significantly with crowding changes.

(5) Data obtained at 12 years of age can be used to predict with almost 70% accuracy whether incisor alignment will improve or worsen by age 18.

(6) In those individuals whose incisors do crowd, the severity of the crowding increase can be forecast with an accuracy of better than 90%.

(7) Prediction of the magnitude and direction of incisor alignment changes at 18 is independant of the degree of crowding at age 12.

(8) The factors responsible for a natural correction of irregularity appear to be different than those responsible for an increase in the severity of crowding.

(9) A highly complex and intricate interaction of numerous craniofacial and dental matrices are involved as factors predisposing to crowding during the normal growth process.

APPENDIX I

DEFINITIONS OF ANATOMIC LANDMARKS AND CEPHALOMETRIC PLANES

A — A point, the most posterior point on the curve of the maxilla between anterior nasal spine and supradentale.

Ar — Björk Articulare, the point of intersection of the inferior surface of the cranial base and the averaged posterior border of the ramus.

B — B point, the most posterior point to a line from infradentale to pogonion on the anterior surface of the symphyseal outline of the mandible.

F — Frankfort Plane, from right to left portion to orbitale.

FOP — Functional occlusal plane, a line connecting the point of occlusion of the most posterior teeth with the point of occlusion of the most anterior bicuspids.

ID — Infradentale, the anterior superior point on the mandible at its labial contact with the mandibular central incisor.

J — Ramus width, width of the ramus along the functional occlusal plane (FOP).

LT — Lingual tuberosity, the lingual tuberosity is derived by extending the distance between the anterior border of the ramus and the posterior border of the ramus (J) along the FOP from the intersection of the FOP and the ramus vertical line.

MA — Mandibular plane, from menton to the gonial intersection.

N — Nasion, the junction of the frontonasal suture at the most posterior point on the curve at the bridge of the nose.

OR — Orbitale, the lowest point on the average of the right and left borders of the bony orbit.

PO — Porion, the midpoint of the line connecting the most superior point of the radiopacity generated by each of the two rods of the cephalostat.

PTM Pterygomaxillary fissure inferior, the most inferior point on the average of the right and left outlines of the pterygomaxillary fissure.

S Sella Turcica, the center of the pituitary fossa of the sphenoid bone.

SD Supradentale, the most anterior inferior point of the maxilla at its labial contact with the maxillary central incisor.

SE Ethmoid registration point, intersection of the sphenoid plane with the averaged greater wing of the sphenoid.

SN Sella Nasion plane, from Sella to Nasion.

APPENDIX 2

CODE FOR IBM KEYPUNCHING

Sex	1 = Male 2 = Female
Angle	1 = Class I Molar Relationship 2 = Class II Molar Relationship
Curve	1 = Flat 2 = Average 3 = Deep

APPENDIX 3

FACTORIAL ANALYSIS OF VARIANCE

I_1 BY SEX AND ANGLE

CLASSIFICATION

Source	SS	df	MS	F	Significance
Main Effects	25.126	2	12.563	2.517	N.S.
Sex	2.274	1	2.274	.456	N.S.
Angle	17.334	1	17.334	3.473	N.S.
Interaction	1.872	1	1.872	.375	N.S.
Explained	26.998	3	8.999	1.803	N.S.
Residual	229.571	46	4.991		
Total	256.570				

APPENDIX 4

FACTORIAL ANALYSIS OF VARIANCE

I_2 BY SEX AND ANGLE

CLASSIFICATION

Source	SS	df	MS	F	Significance
Main Effects	17.264	2	8.632	1.225	N.S.
Sex	1.532	1	1.532	.217	N.S.
Angle	11.959	1	11.959	1.697	N.S.
Interactions	.027	1	.027	.004	N.S.
Explained	17.291	3	5.764	.818	N.S.
Residual	324	46	7.049		
Total	341.546	49			

APPENDIX 5

FACTORIAL ANALYSIS OF VARIANCE

I_3 BY SEX AND ANGLE

CLASSIFICATION

Source	SS	df	MS	F	Significance
Main Effects	.736	2	.368	.172	N.S.
Sex	.073	1	.073	.034	N.S.
Angle	.497	1	.497	.232	N.S.
Interaction	2.351	1	2.351	1.098	N.S.
Explained	3.086	3	1.029	.481	N.S.
Residual	98.445	46	2.140		
Total	101.531	49			

APPENDIX 6

CASES PRESENTING A FAVORABLE CHANGE IN INCISOR IRREGULARITY ($I_3<0$)

Bolton Number	I_1 (mm)	I_2 (mm)	I_3 (mm)
2224	2.5	1.2	-0.7
2285	5.6	4.7	-0.9
2378	1.2	0.8	-0.4
2357	2.4	1.2	-1.2
2418	6.6	4.8	-1.8
2656	3.4	2.1	-1.3
2720	6.7	5.8	-0.9
2768	6.5	5.5	-1.0
3197	9.8	9.6	-0.2
3315	5.3	4.4	-0.9
2207	2.5	2.1	-0.4
2423	2.5	1.5	-1.0
2481	5.5	4.5	-1.0
2553	4.5	3.5	-1.0
3232	3.6	1.1	-2.5
3471	2.4	1.9	-0.5

APPENDIX 7

CASES PRESENTING A SEVERE CHANGE IN INCISOR IRREGULARITY (I_3>1.25)

Bolton Number	I_1 (mm)	I_2 (mm)	I_3 (mm)
141	5.2	6.7	1.5
2232	11.3	13.9	2.6
2480	1.6	3.1	1.5
2565	1.9	4.1	2.2
2574	7.6	8.9	1.3
2815	3.6	5.5	1.9
3308	5.9	9.3	3.4
3312	1.9	3.2	1.3
3066	3.9	6.3	2.4
1167	1.6	2.9	1.3
259	2.6	5.1	2.5
2094	1.5	3.1	1.6
2274	3.6	8.8	5.2
2147	3.1	5.0	1.9
3132	2.0	4.2	2.2
3481	3.1	5.3	2.2

APPENDIX 8

ARCH LENGTH DIMENSION FOR CASES PRESENTING A FAVORABLE CHANGE IN INCISOR IRREGULARITY

(I_3<0)

Bolton Number	$Arch_1$	$Arch_2$	$Arch_3$
2224	31.2	29.9	-1.3
2285	31.9	30.7	-1.2
2378	34.9	33.0	-1.9
2357	32.2	29.1	-3.1
2418	28.8	25.6	-3.2
2656	32.2	31.7	-0.5
2720	25.6	24.9	-0.7
2768	29.7	27.2	-2.5
3197	27.7	26.2	-1.5
3315	31.6	31.1	-0.5
2207	29.7	27.8	-1.9
2423	32.7	31.8	-0.9
2481	26.5	26.4	-0.1
2553	33.6	31.6	-2.0
3232	30.9	27.6	-3.3
3471	27.3	26.4	-0.9

APPENDIX 9

ARCH LENGTH DIMENSION FOR CASES PRESENTING A SEVERE CHANGE IN INCISOR IRREGULARITY

(I_3>1.25)

Bolton Number	$Arch_1$	$Arch_2$	$Arch_3$
141	27.5	27.4	-0.1
2232	26.1	25.6	-0.5
2480	32.5	30.3	-2.2
2565	30.4	28.6	-1.8
2574	28.2	26.7	-1.5
2815	30.4	28.4	-2.0
3308	30.2	28.4	-1.8
3312	32.3	30.7	-1.6
3066	30.3	29.6	-0.7
1167	32.8	31.7	-1.1
259	28.8	28.5	-0.3
2094	30.7	29.0	-1.7
2274	32.3	31.7	-0.6
2147	33.2	31.4	-1.8
3132	31.2	29.8	-1.4
3481	28.4	28.3	-0.1

APPENDIX 10

MOLAR WIDTH AND CUSPID WIDTH DIMENSION FOR THE FAVORABLE CROWDING GROUP (I_3<0)

Bolton Number	$MWID_1$ (mm)	$MWID_2$ (mm)	$Cuspid_1$ (mm)	$Cuspid_2$ (mm)
2224	42.3	40.4	30.2	28.4
2285	40.9	42.9	24.9	26.4
2378	50.5	50.6	29.1	27.8
2357	43.3	43.5	23.4	23.8
2418	42.1	37.6	21.8	21.5
2656	46.2	47.6	27.9	26.9
2720	37.6	36.8	21.2	21.5
2768	42.6	39.8	24.2	22.8
3197	41.9	41.5	43.2	43.2
3315	45.1	46.8	25.7	26.6
2207	35.8	39.4	20.9	20.9
2423	49.7	48.8	25.6	23.7
2481	34.9	34.5	21.5	23.2
2553	46.1	35.4	28.8	26.5
3232	42.7	40.2	24.0	23.1
3471	42.1	44.9	24.6	24.1

APPENDIX 11

MOLAR WIDTH AND CUSPID WIDTH DIMENSION FOR THE SEVERE CROWDING GROUP (I_3>1.25)

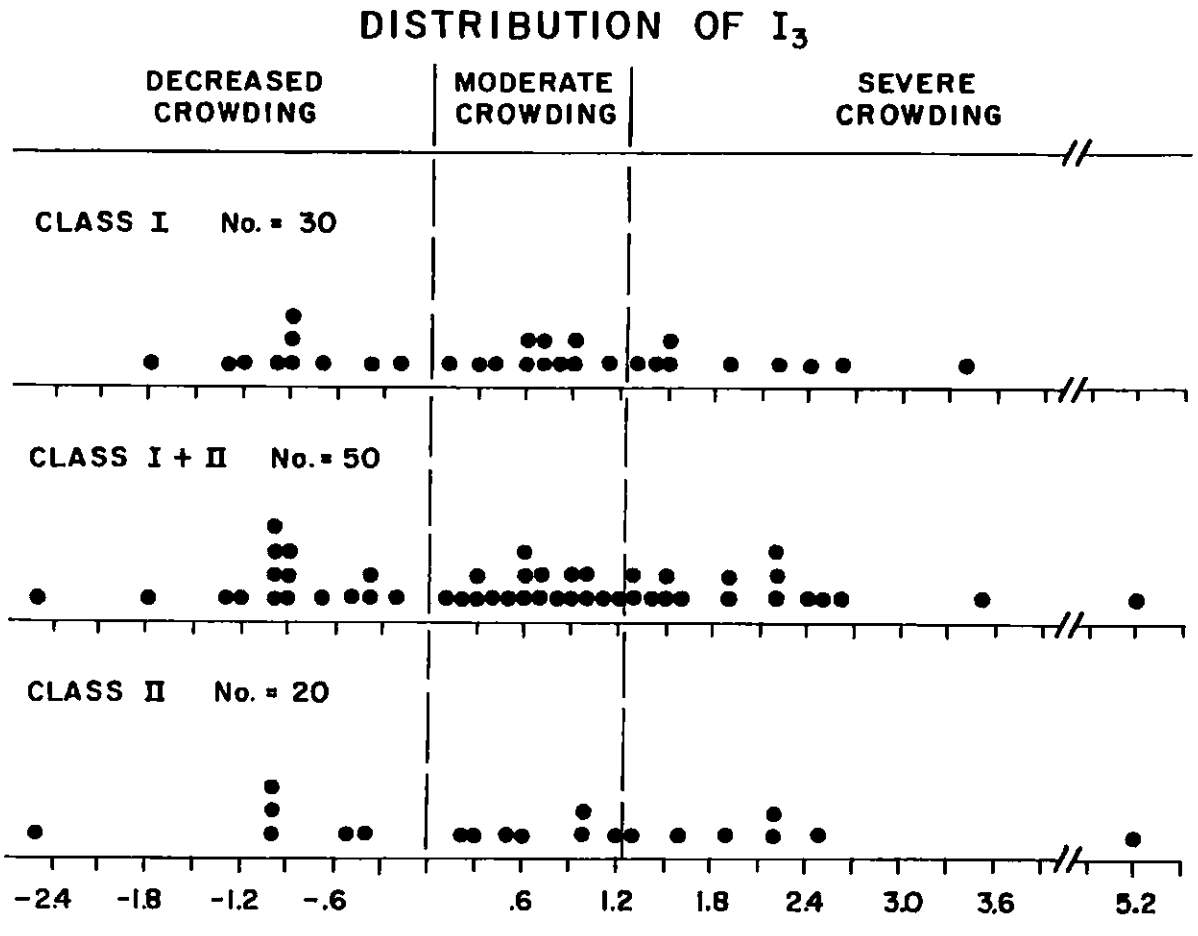
Bolton Number	$MWID_1$ (mm)	$MWID_2$ (mm)	$Cuspid_1$ (mm)	$Cuspid_2$ (mm)
141	44.1	45.7	24.5	23.7
2232	40.0	40.9	21.5	20.3
2480	44.3	44.8	24.6	26.1
2565	43.2	42.2	25.7	25.2
2574	39.6	40.1	22.6	22.4
2815	41.6	39.9	24.5	23.3
3308	42.5	41.8	24.0	22.2
3312	44.6	43.6	26.4	26.8
3066	45.7	44.6	25.1	23.7
1167	44.3	48.3	26.8	28.1
259	51.4	54.5	30.8	31.0
2094	43.8	41.3	22.7	21.3
2274	47.4	36.8	25.7	24.1
2147	35.9	38.6	22.8	22.5
3132	46.2	44.6	28.3	26.5
3481	40.0	40.4	27.0	26.9

APPENDIX 12

The distribution of the change in crowding (I_3) for Angle Class I cases.

The distribution of the change in crowding (I_3) for Angle Class I and Angle Class II, Division 1 cases.

The distribution of the change in crowding (I_3) for Angle Class II, Division 1 cases.


DISTRIBUTION OF I_3
DECREASED CROWDING
MODERATE CROWDING
SEVERE CROWDING
CLASS I No. = 30
CLASS I + II No. = 50
CLASS II No. = 20
-2.4
-1.8
-1.2
-.6
.6
1.2
1.8
2.4
3.0
3.6
5.2

APPENDIX 13

LISTING OF CASES ANALYZED

Angle Classification I

Bolton Number:

141	3047
2224	3149
2232	3066
2252	3197
2285	3204
2378	3268
2357	3299
2418	3308
2425	3312
2480	3313
2565	3315
2574	
2627	
2656	
2668	
2720	
2768	
2790	
2815	

Angle Classification II

Bolton Number:

259
1204
1157
1167
2094
2147
2207
2274
2423
2481
2551
2553
2686
2694
3132
3219
3223
3232
3471
3481

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