OVERBITE: CRANIOFACIAL ASSOCIATIONS, TREATMENT AND POST-TREATMENT CHANGES: A LATERAL CEPHALOMETRIC STUDY

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DEDICATION

This thesis is dedicated to my
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this project a reality.

Overbite: Craniofacial associations, treatment and post-treatment changes, a lateral cephalometric study.

by

Terry Douglas Carlyle

ABSTRACT

Using the digitized coordinates obtained from four serial lateral cephalometric radiographs (pre- and post-treatment, post-retention, two years post-retention) for each of eighty-seven orthodontic patients treated at the University of Manitoba, a study of overbite relationships and changes was performed. The patients were grouped into several categories on separate occasions and the following statistical tests were employed: "pooled" correlations of Angle malocclusion and sex subgroups were assessed to examined the relationship of overbite to various dentofacial measurements; a mixed factorial analysis of variance to examine the effects of extraction versus non-extraction, Angle classification and stage of treatment on overbite and other variables and the same analysis of variance to test extraction versus non-extraction, sample grouping based on depth of overbite and stage of treatment on overbite.

The statistical assessment of the results leads to the following conclusions:

(1) Deep overbites have a complex multifactorial aetiology. The following dental and skeletal factors when examined separately or in combination were associated with overbite:

a) Diminished dentoalveolar vertical heights of the maxillary and mandibular molars.

b) The retrusive relationship of the mandibular incisors (lower incisor to AP).

c) The size, shape and/or position of the mandible. (Smaller or dorsally positioned mandibles may account in part for the strong negative correlations of lower face height, total face height, occlusal plane and mandibular plane and mandibular incisors position with overbite. As well, the morphology and position of the mandible may also play a role in determining the positive correlation of the ANB angle and overjet with overbite.)

(2) The mean vertical dentoalveolar heights of the maxillary and mandibular incisors were not significantly related to overbite in this malocclusion sample.

(3) The effect of the type of treatment (extraction vs. non-extraction) had no significant effect on the treatment and post-treatment changes in overbite.

(4) Regardless of the method of sample segregation (i.e., Angle classes or depth of overbite groups), those patients who exhibited the largest pre-treatment overbite also exhibited the deepest overbite at the end of the two year post-retention period. As

well, these patients exhibited the greatest amount of overbite correction and likewise maintained the greatest amount of correction as a result of orthodontic therapy and/or growth.

(5) Regardless of sample structure, the greatest amount of overbite relapse occurred during the so called retention period, i.e., in this study within two years after termination of active therapy.

(6) Although some dental variables examined were significantly responsible for overbite decrease during treatment, others were significantly related to overbite relapse during the post-treatment periods.

a) Proclination of the mandibular incisors during treatment was strongly associated with overbite reduction. However, the "uprighting" of the mandibular incisors during the retention and post-retention periods accounted for the greatest portion of overbite relapse. This was especially evident in the deep overbite Angle Class II Division 2 malocclusion group.

b) Changes in the axial positions of the mandibular incisors could have also accounted for the changes observed in overjet, interincisal angle and the occlusal plane.

c) Increases in vertical dentoalveolar height of the molar and bicuspid teeth due to growth and/or treatment were partly responsible for overbite reduction. Vertical dentoalveolar heights of the molars were stable following treatment and in fact continued to increase throughout the retention and post-retention periods.

(7) Other craniofacial and dental relationships not examined in this study may have been responsible in part for overbite relapse.

(8) Stability of the incisal segments should take into account the following factors:

   a) The type of mechanics employed to achieve an acceptable overbite (and overjet) relationship. Where indicated "over-torquing and over-intrusion" may be necessary in view of the relapse tendencies observed in this study.

   b) Functional considerations i.e., functional and postural movements of the mandible and their influence on incisal contacts and as well as the effect of the restraining lip musculature on the anterior teeth must be considered. Occlusal adjustment to ensure stable centric relation and other functional position incisal contacts is deemed necessary in the post-treatment periods.

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INTRODUCTION

Evaluation of orthodontically treated patients often discloses a tendency for the corrected malocclusion to return to the original morphologic pattern, although the malocclusion may not be reestablished in its former severity. There is general agreement among orthodontists that certain parameters of corrected malocclusions are more difficult to retain. For example, studies by Schudy (1963), Ludwig (1966) and Simons (1971) have found that some degree of post-treatment return of overbite is the rule rather than the exception.

Some orthodontists refer to post-treatment return of the dentition as "relapse". Relapse according to Webster's New Collegiate Dictionary (1975) is defined as follows: to slip or fall back into a former worse state. Hellman (1944) felt that these relapses were bound to occur even in successfully treated orthodontic cases. The return of the corrected occlusion to its original pattern should not be designated relapse according to Horowitz and Hixon (1971). The term "relapse" can be designated as two basic entities, one termed "physiologic recovery" and the other "normal dentitional changes", that occur throughout the growth period and into adult life. Post-treatment changes such as rotations, arch collapse after expansion and the recurrence of overbite, etc. may be termed a physiologic recovery phenomena. The tendency for physiologic return exists whether or not teeth were extracted in orthodontic therapy and it is not solely related to the type of appliance utilized (i.e., fixed or removable).

The tendency of the teeth to undergo a change of position upon the removal of orthodontic or retention appliances has been attributed to many factors. For example, periodontal ligament tension and supracrestal fibers (Edwards, 1968), post-treatment growth (Singer, 1975), lack of adaptation of the teeth to their new positions and occlusal interferences (Ramfjord, 1974), changes due to band spaces (Hull, 1975) and other factors have been described as factors in concert with physiologic return. When all factors are favourable upon completion of treatment, they help maintain and may actually improve the result obtained.

At present, where the teeth should be positioned so that they will be maintained without relapse, may depend largely upon the clinical experience of the orthodontist. This is often a subjective pragmatic decision. As well, in the past three decades, many cephalometric analyses and treatment "norms" have been advocated by various clinicians or researchers outlining tooth positions which are considered "stable" or even "ideal". For example, Ricketts (in Gugino, 1971) states that the ideal overbite is 2.5 mm, the ideal overjet is 2.5 mm, with an interincisal angulation of 135 degrees where the lower incisor is proclined 22 degrees to the A-Po plane (subnasale A point to pogonion). Begg (1977), on the other hand, says it is abnormal for man to retain an incisor overbite after early adolescence, and the correct incisal relationship is an end-to-end occlusion.

Various methods have been presented in the literature to try to establish an "ideal" value for overbite (Neff, 1949; Bolton, 1958; Moorrees, 1959). Salzmann (1966) states an abnormal overbite is one where the maxillary incisal margin overlaps the mandibular incisal margin by at least 35 percent or more.

Treatment of an abnormal overbite may be based on aesthetic and/or functional considerations or in association with other aspects of a malocclusion (example: a deep overbite may be associated with a tooth-size arch-discrepancy and can be found in any of the Angle classification groups). Deep impinging overbites may cause damage to the periodontal tissues (Dawson, 1974) although Ramfjord concludes from clinical observation that if adequate posterior tooth contact is maintained, deep bite is not a problem. Dawson agrees with this to some extent but he states "that deep overbite is not a problem in itself" as long as there are "stable centric contacts". However, if adequate holding (centric relation) contacts cannot be established, periodontal and functional problems may result. Pain and malfunction of the temporomandibular joint due to functional retrusions and deflective interferences have been reported by Guichet (1970). Hellman (1923) and Popovich (1955) found a correlation between excessive overbite and dysfunction of the temporomandibular joint. They did not, however, assess the dorsal positioning of the mandible. Dawson (1974) also agrees with Guichet that deep overbite does not cause temporomandibular joint problems unless it is a deep overbite associated with lateral, centric and/or protrusive interferences as well. The fact remains, though, that for whatever reason overbite is corrected, it may return towards its original position.

Many hypotheses have been advanced as to the aetiology of overbite and with many of these hypotheses have come treatment plans for correction (Begg, 1977; Schudy, 1968). Based on clinical studies, these authors and others have shown most treatment techniques to be effective in reducing overbite where desired. However, many studies have shown that the degree of correction is not always stable and the reason for this is as yet unknown (Magill, 1960; Simons, 1971).

In the present study, 87 orthodontically treated cases were examined in order to assess the treatment and post-treatment changes in occlusion. More specifically, incisor overbite changes were analyzed as well as other variables related to overbite such as axial inclinations of the upper and lower teeth, vertical changes of incisors and molars as well as skeletal structures (i.e., jaws) due to treatment and/or growth. That the amount of overbite present in any individual may vary throughout their life (Bjork, 1953; Moorrees, 1959; Foster et al., 1972), makes it difficult to assess the stability of a corrected deep bite solely on any one ideal treatment value. Analysis of dental changes alone may be somewhat tenuous: Bjork and Skeiller (1972) have shown with metallic implant studies that growth rotations of the mandible may increase or decrease overbite.

Lavergne (1976) and Gasson (1976) used implant studies in growing children and found that the rotation of the mandible and maxilla was an extremely complex phenomena showing variation in direction and intensity from year to year. No connection was found between the translation and the morphogenesis of malocclusions. Gasson did note, however, that rotation of either the maxilla or mandible may have a more important role in the morphogenesis of malocclusions by influencing the sagittal and the vertical relationships between jaws. If growth rotation of the maxilla and mandible are in harmony, the facial pattern remains rather constant. However, the maxilla and mandible may exhibit opposite directions of their rotations resulting in anomalies of vertical development which may be reflected in the anterior dental units as open bite or deep overbite.

The purpose of this study was to evaluate the following:

(1) The aetiologic factors of overbite to determine if those factors previously postulated in the literature are substantiated.

(2) The effects of treatment and subsequent post-treatment changes of the dental units on overbite.

(3) The changes in the skeletal components of the face which may or may not have some effect on overbite stability.

REVIEW OF THE LITERATURE

CHAPTER II

REVIEW OF THE LITERATURE

Anthropologists have presented evidence that the jaws of man are getting smaller and that there is a developing tendency for a retrusive mandibular pattern as man's evolution continues. Keith (1925) revealed that the upper and lower incisor teeth in adult Neanderthal man occluded in an edge to edge fashion and the vertical overbite became a feature of the Saxon's occlusion over 1,000 years ago. At first he suggested this was strictly functional in nature but to determine clearly the cause of this vertical incisor overlap one must also take into account the Saxon racial "stock" as well as their food.

Begg (1954) in his studies of adult "stone age" Australian aborigines has shown that many of these people had an end-to-end bite with almost no overjet. Form and function, together, had produced a dental apparatus that was well aligned, well balanced with harmony between the three major tissue systems; tooth, bone and muscle. This had developed, no doubt, due to the influence of their environment on their genetic control mechanisms that determines facial growth. With dietary changes and less interproximal and occlusal wear, there has been an alteration within the tooth system itself. Part of this alteration results from different functional demands being made on the tooth system by modern refined foods; part is attributed to a homeostatic or adaptive response to the basal bone modifications as described in anthropologic studies (Moore and Lavelle, 1974). These workers point out that the osseous units under the influence of the musculature (and function) exhibit more dramatic evolutionary changes than do the dental units.

There is still some debate as to what extent evolution and/or function may influence the development of overbite. Murphy (1958) had concluded that skeletal disharmonies following the reduction of the intermaxillary space consequent to tooth attrition were adjusted by condylar growth and remodelling. In his study of 476 adult Australian aboriginal skulls, he determined the degree of functional tooth attrition was important in the amount of condylar growth and gonial angle remodelling. In the most severely abraded dentitions, an edge-to-edge incisor bite was produced along with compensatory changes on the anteriosuperior surface of the head of the condyle and its corresponding surface of the articular eminence.

It seems apparent that man has developed a greater amount of overjet in his dentition and a significantly deeper overbite. Graber (1975) reports that two thirds of all patients now treated by orthodontists have a basal jaw malrelationship with anteroposterior discrepancies reflected in overbite and overjet problems.

Methods of Overbite Assessment

In contemporary orthodontic literature, the term overbite describes the vertical distance which the maxillary incisal edge overlaps the mandibular incisal edge when the posterior teeth are in maximum intercuspation (Strang, 1950). Overjet refers to the horizontal measurement from the edge of the maxillary incisors to the labial surface of the mandiublar incisors. It is generally acknowledged by clinicians in the literature that some degree of overbite and overjet is normal (Fleming, 1961).

While the measurement of overjet is almost universally performed using a millimeter measure (i.e., in clinical, model or cephalometric radiograph analyses), there are at least three techniques of measuring overbite. Bjork (1953) measured overbite in millimeters of lower central incisors covered by the upper central incisors, while Grainger (1966) and Summers (1966) recorded overbite as a ratio of thirds of lower central incisors covered by the upper central incisors. Moorrees (1959) indicated the degree of overbite as a percentage of lower central incisor covered by the upper central incisor.

As there is a great deal of variability in clinical crown size of the maxillary and mandibular incisors, the ratio of percentage method of measurement is preferred. Each of these methods, however, has been employed and reported in the literature making comparison studies somewhat difficult.

Neff (1949), expressing overbite as a percentage of the lower incisor covered by the corresponding upper incisor, felt that 20 percent was ideal. By measuring the mesiodistal diameter of the six upper anterior and lower teeth on 200 cases he derived an anterior coefficient to determine the ideal overbite.

In a similar study of tooth measurements, Bolton (1958) measured the mesiodistal widths of maxillary and mandibular teeth from first molar to first molar. In these 55 cases of "excellent occlusion" the mean overbite was calculated to be 31.3 percent, however, there was a great deal of individual variation. Of these 55 cases, 44 were patients who had been treated orthodontically but had no extractions. The remaining 11 cases had no orthodontic therapy. No mention was made of age ranges, sex or ethnic composition of the sample. Bolton applied Neff's anterior coefficient to this sample and was unable to reproduce Neff's results.

Orton and Lischer (1933) in an epidemiologic study of 2,982 first year college students (1,498 males and 1,587 females) found that 48 percent of the males and 53 percent of the females had a two to three millimeter overbite. The ranges of overbite for males and females were both considerable.

Steadman (1952) in a radiographic study of dental models of 47 acceptable occlusions found the mean overbite to be 3.1 ± 1.9 mm with a range from 0.5 mm to 4.3 mm. No breakdown of the sample as to sex or age was mentioned.

Bjork (1953) examined the incisor relationship of 322 twelve year old Swedish boys and reported mean values for overjet of 4.1 mm and for overbite of 2.6 mm.

Fleming (1961) recorded the overbite of 74 twelve year old children with Angle Class I occlusions and reported a mean overbite of 4.37 mm.

Fulton et al. (1965) found a mean overjet of 3.18 mm and a mean overbite of 3.24 mm in a randomly selected group of 977 children between the ages of ten and nineteen years. They reported no significant differences between the sexes.

Summers (1966) in an investigation of 96 twelve year old Caucasoid children, reported a mean overjet of two to three millimeters and a mean overbite of zero to one-third of the lower incisor crown covered with no significant differences between the sexes.

Beaton (1973) studied 48 twelve year old Caucasoids with acceptable occlusions. Using lateral cephalometric radiographs, the mean overbite for this group of Winnipeg school children was found to be 3.11 ± 0.94 mm for the males (21) and 3.00 ± 1.05 mm for the females (27). The mean overjet for the males was 2.99 ± 0.90 and for the females 2.62 ± 0.72 mm. There were no significant differences between the sexes.

These studies and many others have shown that overbite as a distinct entity is variable and the borderline between acceptable and unacceptable, for a given individual, remains to be clearly defined.

Effects of Facial Growth on Overbite

Not only is there variation in the amounts of incisal overbite, but also there is variation in the effects of growth of the craniofacial complex on overbite changes. Moyers et al. (1976) in a longitudinal study of 208 Caucasoid children of North European ancestry (age 3 years to 18 years) found that the mean overbite tended to increase with age in the deciduous dentition and that the mean overbite in the permanent dentition showed a plateauing effect at approximately age twelve to fourteen years in both males and females. The greatest mean overbite that occurred at age 13 for the males was 3.48 ± 1.82 mm and for the females 3.25 ± 1.49 mm. On an individual basis there was a great deal of variability. These workers used an "Optocom", a microscope designed to accurately measure dental casts.

Earlier studies have confirmed this trend of overbite stabilization after eruption of permanent teeth. Barrow and White (1952) examined serial dental casts of 58 children and determined that overbite tended to remain more stable after eruption of the permanent bicuspids and second molars. It should be pointed out that the sample used in this study composed a portion of the larger sample used by Moyers et al. (1976).

Bjork (1953) found a slight decrease in the mean overbite (0.55 mm) in 322 Swedish males from age twelve to twenty. This was accompanied by a large variation between individuals that ranges from an increase of 5.0 mm to a decrease of 5.0 mm (S.D. ± 1.55 mm). Deep overbites tended to open more than the more "normal" overbite group.

Bjork and Skeiller (1972) studied 9 females and 12 males at adolescence. Implants were placed in the maxilla and mandible and analysis of serial radiographs showed that the growth rotations of the mandible may effect dental compensations and that overbite was strongly correlated with rotation of the mandible.

Baume (1950) and Moorrees (1959) observed a slight decrease in the mean overbite of Caucasoid children in their respective longitudinal studies. Moorrees found that the mean proportional amount of overbite is quite similar in the deciduous dentition at age five to six years and in the permanent dentition at age sixteen to eighteen years (35 to 40 percent). Overbite was slightly greater at all ages in females, however, this finding was not statistically significant. The large standard deviations reported by both these authors in their studies shows a wide range of values and thus great individual variability in their samples.

Bhatia and Leighton (1971) studied serial records of 10 "deep" bite (overbite greater than 5 mm) and 10 "shallow" bite (overbite less than 2 mm). These Caucasoid children were all between the ages of 5 1/2 and 13 1/2 years of age. Analysis of the results for this small sample confirmed the variability of the change in overbite over the time period studied. This confirms the results of Baume (1950) and Moorrees (1959).

Foster, Grundy and Lavelle (1972) studied 40 male and 30 female British Caucasoids from age 2 1/2 to age 5 1/2 years. They found no consistent change in overbite other than there was more variation than incisal overjet with increasing age. A mean overbite reduction of 1.34 mm occurred in 27 subjects and a mean overbite increase occurred in 24 subjects. Of the 53 subjects that had deciduous incisors at 5 1/2 years of age only 2 had shown no change in overbite. The ranges for the overbite changes were considerable and the authors concluded that prediction of final overbite could not be made due to great individual variation.

Herness et al. (1973) in a longitudinal cephalometric and dental model study of 11 female and 9 male Caucasoids (age 5 to 11 years) found that overbite increased steadily during this time period. Boys had larger overbites than girls at all age levels studied, but the differences were not significantly different. This was a very small sample hence the results may be misleading as this group was selected on the basis of Angle Class I occlusion alone.

It can thus be seen that the changes in overbite during growth of craniofacial structures is variable. A more in-depth analysis of overbite as it relates to specific entities such as, eruption of teeth, growth of the mandible, etc., should probably have been examined in conjunction with measurement of overbite changes. This may have helped elucidate information as to some of the more specific so-called aetiologic factors of overbite.

Specific Aetiologic Factors Relating to Overbite

Man's evolutionary trend has resulted in production of a variable amount of overjet and overbite which in turn has resulted in this being accepted as the rule rather than the exception. Orthodontists, in attempting correction of overbite, have often tried to ascertain which specific component or components of the craniofacial complex are responsible for the production of overbite. The following entities have been studied as aetiologic factors:

A) Dental Factors

(i) Cusp height of teeth - Bonwell, 1925; Mershon, 1937; Popovich, 1955.

(ii) Vertical dentoalveolar height and curve of Spee (infraclusion, supraclusion) - Strang, 1934; Wylie, 1946; Fleming, 1961; Schudy, 1968.

(iii) Axial inclinations of central incisors - Steadman, 1949; Schudy, 1968.

B) Skeletal Factors

(i) Horizontal growth of the mandible - Mershon, 1937; Baume, 1950; Dempsey, 1974.

(ii) Vertical growth of the ramus of the mandible - Diamond, 1944; Wylie, 1946; Popovich, 1955; Fleming, 1961.

(iii) Rotations of the mandible due to growth - Bjork and Skeiller, 1972; Gasson, 1976; Lavergne, 1976.

(iv) Facial types and musculature - Moller, 1966; Sassouni, 1969; Subtelny, 1970.

A. Dental Factors

In his work on artificial teeth, Bonwell (1925) stated that the overbite in the incisor region was governed by the depths of the cusps of the molars and premolars which vary in different individuals. Mershon (1937) described two types of closed bites, one being a true closed bite in which the teeth are short and broad thus making the distance between the mandible and the maxilla unusually short. The second type of closed bite was really a deep overbite which had posterior teeth with long deep cusps and an exaggeration of the curve of Spee as the result of overeruption of the lower anterior teeth. These descriptions by Mershon were based on clinical examination only.

Popovich (1955) in a study of 51 males and 51 females (aged

18 to 25) corroborrated the work of Bonwell. Using dental models and lateral cephalograms, Popovich found the factors contributing to excessive overbite varied with the type of occlusion. In the "ideal occlusion" group (17 males and 17 females) the amount of overbite was determined largely by dental factors. A strong positive correlation (r = 0.730) was detected between the overbite and cusp height. In the Angle Class I malocclusion group with deep overbite (more than 4 mm), the overbite seemed to be controlled by dental factors which he listed as length of the upper incisors (r = +0.430) and length of the upper incisor crown (r = 0.440). Other factors such as cusp height showed significant changes in average dimensions when compared to the control group. In the Angle Class II group, skeletal factors were found to be more associated to overbite than dental factors except the interincisal angle (r = 0.730). Popovich concluded that dental factors alone were not responsible for overbite.

The vertical height of the dental units relative to certain cepahlometric planes and/or curve of Spee is another factor that has been studied extensively. Strang (1934) associated excessive overbite with what he termed "infraclusion" of the posterior teeth or "supraclusion" of the anterior teeth. From clinical and photographic examination of his orthodontic patients, he determined which of these factors were responsible by judging the proportion of the patient's lower face (tip of nose to chin) to the upper face (tip of nose to glabella). If these appeared "harmonious", he attributed the problem to the supra-eruption of the incisors. If the lower face appeared disproportionately small, he attributed the excessive overbite to infraclusion of the posterior teeth. The validity of such a subjective assessment as this is to be questioned. However, it represents a somewhat crude attempt at possibly assessing the skeletal pattern as well.

Wylie (1946) found a statistically significant difference in vertical molar height between slight, medium and deep bite groups. He analyzed the pretreatment lateral cephalometric radiographs of 90 patients (61 females and 29 males). No age range was given. Composition of the three groups was based on the assessment of overbite alone:

(i) slight overbite (24) - the mandibular incisor edges contacted the incisal third of the lingual of the maxillary incisors.

(ii) medium overbite (27) - the mandibular incisal edges contact the middle third of the lingual of the maxillary incisors.

(iii) severe overbite (39) - the mandibular incisal edges contacted between the cingulum and the palatal tissue of the maxillary incisors.

In his sample of 90 patients, 66 had medium to severe overbites. The distance from the palatal plane to the mandibular plane through the first permanent molars was found to be 3.5 mm less in the deep overbite group. The difference between the shallow overbite and the moderate overbite group was not significant. The absolute values given must be interpreted with care, as Wylie mentions that he did not correct any values caused by cephalometric enlargement.

Prakash and Margolis (1952) studied cephalometric radiographs of 120 randomly selected individuals between ages 12 and 30 years. No breakdown of the group according to sex was given. They found a negative correlation ($r = -0.450$) between the lower molar height (lower molar to mandibular plane) and overbite. As well, overbite was positively correlated ($r = 0.400$) to upper incisor height (tip of maxillary incisor to nasion). Vertical position of the lower incisors showed no association with overbite.

Statistically significant ($p < 0.02$), but low negative relationships ($r = -0.218$ and $r = -0.238$) were found between posterior maxillary and mandibular alveolar heights and overbite in male Angle Class I patients by Fleming (1961). When the male and female groups were combined, these variables no longer correlated with overbite. In Fleming's female group, the lower incisor vertical height had a positive but low correlation with overbite. This was contrary to the findings of Prakash and Margolis (1952) who found no association of this variable to overbite and may have been due to the heterogeneous nature of the latter's sample.

Based on clinical observations and cephalometric analysis of 400 patients aged 9 to 18 years, Schudy (1963, 1968) determined that downward growth of the posterior maxillary teeth played an important role in overbite determination. Excessive growth of these teeth caused a decrease in overbite while deficient growth caused an increase in overbite. Vertical growth of the lower molars plays a minor role in overbite determination during growth of the face.

As mentioned earlier, Prakash and Margolis (1952) found that the vertical length of the anterior maxillary dentoalveolar unit had a small but positive correlation with overbite. Vertical growth of the incisors has been implicated in the aetiology of overbite. Smeets (1962) found only the lower incisor vertical height to be associated with overbite. Fleming (1961) found significant but low correlations for the upper jaw only in females, and in the combined male and female groups for the lower incisor only ($r = 0.208$). Bjork (1947) and Issacson (1970) could find no significant correlations between vertical incisor height and overbite except in extreme cases. Mills (1973) found low positive correlation coefficients ($r = 0.246$) for the upper and lower incisor heights indicating a very slight trend to overeruption in deep bite cases (Angle Class II Division 2). He analyzed lateral cephalometric radiographs of 39 females and 21 males aged 11 to 18 years. Mills did find that overbite was highly correlated ($r = 0.767$, $p < 0.001$) to the interincisal angle.

Steadman (1949) was one of the first authors to stress the relationship of the long axis inclinations of the maxillary and mandibular incisor teeth to each other as a prime aetiologic factor in overbite. He reported that overbite increased as the interincisal angle increased, and likewise decreased as the interincisal angle did. Popovich (1955) confirmed this relationship in his Class II deep overbite groups ($r = 0.730$). The relationship for the Angle Class I malocclusion and "normal" group were positive but low ($r = 0.210$). Popovich's Class II group was not defined, hence the higher value could have been due to a bias towards a deep overbite group that exhibited Angle Class II Division 2 characteristics.

Herness et al. (1973) found that overbite was significantly correlated with the interincisal angle in their Angle Class I occlusion group at ages 5, 7, 9 and 11 years. They reported a mean increase in overbite for each age level yet the mean interincisal angle decreased from $143.4^{o} \pm 8.2^{o}$ at age 5 to $130.2^{o} \pm 7.0^{o}$ at age 11 years. Their sample size, however, was quite small (18) and there was a great deal of variation in both overbite and the interincisal angle. This variation was confirmed in an earlier study by Bhatia and Leighton (1971).

Schudy (1963, 1968) has placed a great deal of emphasis on the axial relationship between the maxillary and mandibular central incisors and overbite. He notes that when a deep overbite develops, accompanied by high interincisal angle, the overbite tends to force the crowns of the maxillary incisors lingually and the apices of the maxillary incisors labially. This, in turn, increases the interincisal angle more which results in a still greater overbite.

Bachlund (1958) examined 255 cephalometric radiographs of a Angle Class I, Class II Division 1, and Division 2 groups (ages 9 to 30 years). He examined the angulation of the lingual surface of the maxillary central incisors and their contacts with the lower incisors. He found this angular relationship to be more meaningful than interincisal angulation in relation to the stability of overbite.

Andrews (1972) in a study of "nonorthodontic individuals" with normal occlusions observed six "keys" to occlusion. They are as follows:

(1) Molar relationship

(2) Crown angulation, the mesiodistal tip

(3) Crown inclination (labiolingual or buccolingual inclination)

(4) Rotations

(5) Spaces

(6) Occlusal plane

By measuring the interincisal crown angle (i.e., long axes parallel to the labial surfaces of the crowns) he determined a mean value of 174° was necessary so that proper distal positioning of contact points of the upper teeth in relation to the lower teeth would permit proper posterior occlusion and overbite. The mean interincisal root long-axis angle in these cases was 139°. No range or standard deviation was determined. This latter value, however, compares with that of other studies - Schudy (1968), Issacson (1970), Mills (1973). Andrews noted that the proper interincisal inclination was complementary to overbite and helped prevent overeruption of incisors.

Issacson (1970) and Mills (1973) both agreed that a high interincisal and deep overbite were related but whether or not there was a definite cause and effect relationship between the two as Schudy (1968) implied, remained to be seen. Mills agreed with Fleming (1961) when he stated that the aetiology of overbite is multifactorial and no single dental parameter was responsible, in fact, close scrutiny of the skeletal complex was necessary.

B. Skeletal Factors

Grieve (1928) determined from clinical examination that the skeletal structures influenced overbite. He described deep overbite not as an entity itself, but rather as a symptom of maxillary protrusion or a lack of mandibular growth. The distal relation of the mandible was responsible for the deep bite.

Baume (1950) concluded that horizontal mandibular growth or lack of it was important in determination of overbite. From his longitudinal study of 52 patients before and after eruption of permanent incisors, he found that the less the amount of forward growth during eruption of these teeth occurred, the deeper was the final overbite.

In his textbook, Salzmann (1966) stated that deep overbite was due to the lack of forward growth of the mandible and associated with this was a lack of vertical development of the ramus and restricted growth of the alveolar processes. No information was provided as to how he came to these conclusions.

Vertical development of the ramus was studied by Diamond (1944). His analysis was based on the composite cephalometric tracings of Broadbent (1937), models of 12 children with delayed eruption and 1 serial study from birth to 8 years and a review of the literature. He hypothesized that "retardation" of the ramus length growth due to "metabolic factors" inhibited the eruption of the posterior teeth but did not interfere with eruption of the anterior teeth, thus resulting in an excessive overbite. No definition of the "metabolic factors" was given.

In testing Diamond's hypothesis, Wylie (1946) compared the ramus length of those cases with slight overbite (1.5 to 2.0 mm) and with those of severe overbite and failed to find any significance between the two groups. Wylie did note, however, that total face height, lower face height and the intermaxillary space in the molar region were significantly less in cases with moderate or severe overbite than in those with slight overbite.

Fleming (1961) stated that overbite was related to a number of craniofacial dimensions of which length of the ramus (shorter in deep bite cases) was found to have a significant but low negative relationship to the degree of overbite in males and females. The relationship was greater in males ($r = -0.372$, $p < 0.01$). These findings tended to agree with Diamond's (1944) hypothesis. Popovich (1955) found a negative correlation ($r = -0.370$, $p < 0.05$) between overbite and ramus length and overbite in his normal and Angle Class I malocclusion groups. Wylie's (1946) results may have been obscured as he did not segregate his sample based on the Angle classification as did Popovich (1955) and Fleming (1961).

Various other skeletal parameters have been stressed as important in overbite assessment. Wylie (1946) found that the lower face height (anterior nasal spine to gnathion) was substantially larger in patients with slight overbite (67.6 mm) than those with moderate overbite (61.7 mm) or severe overbites (60.0 mm). The total face height (nasion to gnathion) reflected the same pattern. Similar results were reported by Prakash and Margolis (1952) for the anterior total facial heights. Lower facial height was not measured by these workers.

Popovich (1955) reported the correlation of total anterior face height to overbite in the Angle Class I "ideal" occlusion group to be r =-0.600 while in the Angle Class II group r =-0.330 ($p < 0.05$). Even though lower face height was significant for the Angle Class II group ($r = -0.520$, $p < 0.01$) no such relationship could be determined for the other two groups. Mills (1973) found similar results for lower face height and overbite in his Angle Class II Division 2 group ($r =-0.355$, $p < 0.01$).

Weinberg and Kronman (1966) studied 30 "normal" occlusions (11 males and 19 females, ages 11 to 12.8 years) and 30 malocclusions (cases with overbite greater than 5 mm and no other criteria for classification was used). This latter group was composed of 10 males and 20 females aged 8.4 to 13.9 years. Cephalometric evaluation showed that the percentage of lower face height was less in the malocclusion group than the control group, yet the results were not significantly different. After "satisfactory" overbite correction they found little change in the lower face height dimension, however, the vertical height of the lower incisors was altered as they were intruded during orthodontic therapy and this in part accounted for the overbite correction.

In a 1970 article on cephalometrics, Subtelny points out that assessment of the upper face height to total face height and "freeway" space may elicit information as to the true nature of overbite. An excessively high percentage (greater than 43 percent, UFH/TFH) in conjunction with an "excessive freeway space" (no value was given) and a deep dental overbite is indicative of a closed bite with a poor vertical relationship of the jaws when the teeth are in occlusion. On the other hand, when the upper face height to total face height is proportionate (43 percent, as first discussed by Brodie, 1941) with a "nearly average freeway space" with the anterior teeth in deep overbite this then is indicative of a deep dental overbite. Treatment is thus dependent upon the correct diagnosis. In the former situation, Subtelny advocates increased posterior dentoalveolar height as the treatment of choice to correct the malocclusion and facial form. In the latter, depression of the anterior teeth may be indicative.

Bjork (1960) has studied overbite and assessed the problem as either dental or skeletal overbites. A dentoalveolar deep overbite may occur when overjet is excessive and there is no contact between the maxillary and mandibular incisors thus allowing overeruption to occur.

The basal or skeletal deep overbite may arise in various ways according to Bjork (1960). In the "secondary closed bite" due to the extraction or premature loss of deciduous molars and first permanent molars, the remaining portion of the dentition may be vertically unstable and the two arches pressed into each other. The mandible consequently rotates counterclockwise and a deep overbite is the result.

The true skeletal overbite as described by Bjork (1960, 1969) may arise as a consequence of facial growth. When there is over-development of the posterior face, the mandible rotates counterclockwise with the center of rotation in molar-premolar region. If the overjet is such that there is no incisor contact or the incisors are vertically inclined, a deep overbite results.

The effects of this growth rotation was described in part by Bjork (1969) but was dramatically seen in Bjork and Skeiller's (1972) implant study of 21 adolescent children. Change in overbite was inversely correlated with the curvature and direction of condylar growth and rotation of the lower jaw (r = -0.790). The inclination of the mandible to the sella nasion plane (MP to SN) was also correlated strongly with overbite (r = -0.730).

The implant study of Gasson (1976) and Lavergne (1976) confirmed the results of Bjork and Skeiller (1972). Gasson and Lavergne studied 30 Norwegian children (17 males, 13 females) aged 7 to 18 years with serial lateral cephalograms and found that rotations of the maxilla as well as the mandible determined the vertical and sagittal relationships of the jaws and teeth.

Studies in man evaluating the relationship between form and function in the masticatory system are few. Mershon (1937) stated that "heavy masticatory musculature" was partly responsible for a "true closed bite". Mershon gave no evidence to support this statement.

Møller (1966) in an extensive electromyographic, lateral cephalometric and dental model study of 36 young adult males (aged 20 to 30 years) attempted to relate the activity of the masticatory system to facial morphology. He found that the mean maximal voltage of the masseter and anterior temporal muscles in maximal clench was associated with a flat mandibular plane to cranial base (SN to MP, r = -0.350), a small gonial angle (r = 0.330) and mandibular protrusion (S-N-Pg). Activity of the posterior temporal muscle was associated with overbite (r = 0.400). These factors were associated with the square facial type and presented often with a deep overbite. Analysis of the dental models showed that the overbite was 3.4 ± 1.5 mm with a range of 0.00 to 7.0 mm.

Sassouni (1969) reported that skeletal deep bite usually is seen in subjects with a smaller gonial angle and "square" facial type. Associated with this facial pattern was a "heavy masticatory musculature". He visualizes the deep bite person as having a vertical chain of masticatory muscles well forward of the molar resistance, where it serves to keep the buccal teeth depressed. In the open bite skeletal type, these muscles exert an oblique force posterior to the molar resistance. The "heavy" musculature was demonstrated by the use of the "gnathodynamometer" a device to test the molar biting force. In the open bite facial types, the molar biting force ranged between 50 to 80 pounds (22.8 to 36.3 kilograms) and in the deep bite skeletal types between 150 to 200 pounds (68.1 to 90.9 kilograms) (Sassouni, 1971). No sample breakdown was listed.

Storey (1975) points out that use of the "gnathodynamometer" should be carefully examined in view of the fact that this instrument does not assess the direction of the force vector. If the applied force is oblique in relation to long axis of the tooth as would often occur in the open bite skeletal pattern, a reflex response inhibiting the masticatory muscles may result because of activation of a greater number of receptors in the periodontum (Storey, 1977). Sassouni (1971) also did not elucidate any information on relative size of the muscles which may have affected his results.

Assessment of any single parameter as the "specific" aetiologic factor is at best tenuous. Early orthodontic literature dealt only with vertical and horizontal positions of the teeth and their relationship to overbite (Strang, 1934; Mershon, 1937). No doubt the advent of cephalometrics as a research and diagnostic tool lead others to scrutinize the underlying skeletal structures more closely as possible aetiologic factors associated with overbite (Wylie, 1946; Popovich, 1955). Finally, analysis of longitudinal growth studies has helped to elucidate information as to the description of changes in overbite (Moorrees, 1959) and possibly, why and how the variability in age changes occur (Bjork and Skeiller, 1972). Increased awareness of the skeletal pattern has in turn progressed to a study of the functional components of the craniofacial complex and the interaction of form and function (Møller, 1966; Sassouni, 1969).

Orthodontic Treatment and Retention Aspects of Overbite

A. Methods of Overbite Treatment

In the literature, there seems to be contradictory opinions as to how overbite should be corrected. This, no doubt, reflects the fact that the aetiology of overbite and its various relationships are not completely known. It is generally agreed among clinicians that "bites" are opened during treatment either by vertically intruding incisors (Begg, 1977) or extruding molars (Schudy, 1968) or a combination of the two (Simons, 1971). The biologic basis underlying these movements has been explained by Reitan (1969, 1975).

Based only on clinical observations, Mershon (1937) maintained that only incisor intrusion would correct and ensure the stability of deep overbite problems. Elongation of posterior teeth would produce unstable results because extrusion of molars would cause a constant strain on the musculature and subsequent to completion of therapy, the forces of mastication would cause the molars to intrude and overbite to return. This suggestion was reiterated by Wylie (1946).

Cole (1948) studied cephalometric radiographs of 21 orthodontically treated patients at least one year out of retention. All had four first bicuspids extracted. Although incisor depression had occurred in therapy, the mesial and extrusive movements of the molars that also occurred, exceeded the "original freeway space" and as a result the "muscular balance" restored the original freeway space by intrusion of molars and as a result, overbite increased. Extraction therapy, he concluded, tended to increase the post-treatment overbite greater than original value. No sample breakdown as to age, sex or type of malocclusion was given.

Hopkins (1940) questioned overbite stability in those cases treated with molar extrusion alone. Based on his clinical experience he agreed with Hemley's (1938) observations that with bite planes molar growth occurs, however, no evidence had been presented to assess the post-treatment stability of these teeth.

Popovich (1955) also agreed with Hopkins (1940) and Cole (1948) that incisor intrusion would be the most logical approach in treatment of overbite. This theory is also a major tenet of the Begg mechanotherapy (Begg, 1977).

Hemley (1938) used anterior bite planes to allow for extrusion of the posterior molar teeth as he noted that clinically this was the most stable form of overbite treatment. Using calipers, Hemley measured 9 deep bite cases (Angle Class II Division 2) from lower incisor and lower molar to the lower border of the mandible and presented modest results showing molars had extruded while incisor height had not changed. No mention was made of how the study was performed, i.e., in vivo, or radiographically.

Schudy (1963, 1968) has placed much emphasis on molar extrusion for overbite. In the untreated individual posterior maxillary, alveolar growth accounts for reduction of overbite. However, in the orthodontically treated individual, Schudy noted that the vertical alveolar growth of the posterior alveolar process of the mandible, greatly exceeds that of the maxilla and, thus, in treatment provides the greatest contribution to overbite correction. Mandibular anterior alveolar response is more variable. Schudy explains that although the mandibular incisors can be readily intruded, they have a strong tendency to relapse during retention. Schudy thus prefers molar extrusion to occur especially in cases where his major diagnostic criteria, the occlusal plane-mandibular plane angle (OM angle) is less than 8 degrees. Increases in this angle signify a change in the vertical height of the lower molars and hence are desirable for stability.

Burstone (1977) notes that most deep overbite correction is produced by extrusion of posterior teeth. According to him, this type of treatment is successful in patients who exhibit a "considerable" amount of mandibular growth. Differential treatment planning should indicate the relative amount of anterior intrusion and posterior extrusion be determined before treatment and that proper "differential mechanics" be utilized to produce the desired correction. The Class II patient, according to Burstone, benefits most from incisor intrusion, as extrusion of posterior teeth will increase the vertical dimension, encroach upon freeway space and ultimately make the face more retrognathic.

B. Post-Treatment Changes Affecting Overbite

Fogel and Magill (1970) studied 10 males and 11 females, 14 years (mean value) out of retention. They attributed overbite correction primarily to extrusion of mandibular molars. They also found that there was no correlation between the interincisal angle and overbite stability. In all cases where overbite increased following retention, extrusion of mandibular incisors was observed.

Cole (1948), Litowitz (1948) and Simons (1971) found in their respective studies that, incisors that were intruded during treatment, tended to extrude during retention and post-retention. Cole (1948) noted a strong tendency for the axial inclination of the mandibular incisors to return to their original relationship with the mandibular plane, after the retention appliances were removed.

Litowitz (1948) studied 15 Angle Class I and 5 Angle Class II malocclusions that were treated non-extraction. Analysis of lateral cepahlograms and dental models at pre- and post-treatment and post-retention (1 to 5 years) revealed that lower incisors tended to return to their original position and subsequently overbite increased. Both the increase in arch length and gain in arch width produced by treatment tended to decrease following treatment.

Thompson (1965) found that the upper and lower incisor height increased during and after retention but, incisor position remained intruded in all groups except the Class I non-extraction group. He also found that the maxillary and mandibular molar heights increased both during and after retention in all groups.

Simons (1971), in a study of 70 orthodontically treated cases, at least 10 years out of retention found that depression as well as protrusion of the mandibular incisor during treatment were both significantly correlated with relapse in overbite. He concluded that deep overbite should be treated by avoiding protrusion or intrusion of lower incisors. The initial mandibular incisor position was deemed to be in a stable balanced position in an anteroposterior and vertical direction. As well, he found the more stable overbite corrections were associated with extrusion of maxillary and mandibular molars.

Menzies (1975) in a study of 20 Begg treated (10 males and 10 females) cases found that at the end of treatment, the mandibular molars had increased vertical heights. In this sample of Angle Class II Division 1 patients, he concluded that overeruption of lower molars during treatment seemed to be the primary factor in overbite correction and increased lower face height.

The general consensus seems to be that the vertical and horizontal stability of the lower incisors is questionable (Cole, 1948; Simons, 1971) and that molar extrusion provides for a greater degree of stability for overbite correction (Schudy, 1968; Simons, 1971; Menzies, 1975).

1. Effect of Extraction Therapy on Overbite Treatment and Stability

The question of extraction and nonextraction has been debated as to the further cause of overbite following retention (Cole, 1948). Using cepahlometric radiographs and model analysis, Magill (1960) studied 63 four first bicuspid extraction cases at least one year out of retention. The sample was composed of 29 Class I and 34 Class II cases between age 10 and 13 years. No breakdown as to sex or Angle Class II group was given. All cases showed a reduction in overbite during treatment and 26 cases continued to show a decrease in overbite following treatment. The pre-treatment shallow overbite group (10 cases) tended to close more than the deep pre-treatment overbite group. Every patient with an original deep overbite showed less overbite after treatment than before. The mean overbite decreased from 5.85 to 3.75 mm, a decrease of 2.48 mm. This was followed by a 0.71 mm (30 percent) relapse. Magill noted that if overbite return does not occur, it will do so within 2 years after the removal of the appliances. He concluded that proper diagnosis and mechanotherapy would rule out the effects of extraction or non-extraction.

Huggins and Birch (1964) found that 69 percent of their sample with deep overbite (64 patients) exhibited relapse changes which occurred within 6 months of appliance removal and was relatively stable thereafter.

Ludwig (1966) studied 114 cases at least 2 years out of retention. In his non-extraction group (94) only 2 cases returned to the original overbite and only one increased slightly beyond the original overbite. Seven cases showed a decrease following the retention period. The mean overbite relapse was 33 percent. He concluded that variation of "anatomical dimensions" and lingual contours of the maxillary incisors may be important in determination of the final overbite; all incisal relapse took place within a year or two; and determination of the overbite relapse must be based on the individual and not on the amount of overbite established at the end of treatment. Extraction had no effect on overbite stability.

Hernandez (1969) related overbite to mandibular bicanine width. He found that most overbite relapse occurred in non-extraction cases in which the mandibular canine width contracted during treatment and continued to contract in the post-retention period. The greatest amount of overbite relapse in extraction cases (25 of 83 Angle Class II Division 1 cases) occurred when the bicanine width was increased during treatment and decreased after treatment. The least overbite relapse occurred in four cases in which no change in mandibular bicanine width was observed.

Hechter (1976) in an unpublished thesis corroborated the results of Hernandez (1969). In his dental model study of 67 patients at pre- and post-treatment and post-retention, he noted that there was a greater relapse of overbite in extraction cases. This was associated in those cases that experienced a post-treatment decrease in inter-canine width. Hechter showed, however, that there was still a net decrease in the mean overbite in his sample in spite of the post-treatment changes in the intercanine widths.

In a cepahlometric analysis of 12 patients with metallic implants, Willbanks (1975) studied the effect of extraction versus non-extraction on vertical changes of facial height. In this study, no discernible effects on vertical development could be detected in either group. Lower molar eruption contributed to 85 percent of the total vertical increase of the face and also to the decrease in overbite. The small sample size may obscure the results of overbite changes. Another interesting observation reported was the fact that resorption along the border of the mandible was present in 7 of the 12 cases and as a result the SN-MP angle decreased. This is also reported by Bjork and Skeiller (1972) and Mills (1973).

In an earlier cephalometric study of 100 treated orthodontic patients with a pre-treatment overbite of 5 mm or more, Ludwig (1967) found that there may be a positive correlation (r = 0.560) between the interincisal angle and degree of overbite at pre-treatment. Post-treatment evaluation showed a slight association (r = 0.260) of overbite and the interincisal angle. In this sample, all of whom had been out of retention from 2 to 8 years, he was unable to show any significant correlation between facial pattern based on dental height depth ratio and the amount of overbite. Extraction was not examined as a significant variable in the relapse of overbite.

This latter thought has been expressed by Nemeth and Issacson (1974). These workers studied dental casts and lateral cephalometric radiographs of 26 patients selected on the basis of return to deep overbite or open bite after orthodontic therapy. Changes in maxillary and mandibular incisor angulation and changes in maxillary and mandibular molar heights were analyzed with respect to "anterior vertical relapse". They concluded that combined sutural and alveolar growth of the maxilla and alveolar growth of the mandible was larger than the posterior facial height increase in anterior deep overbite relapse. Forward mandibular growth was exhibited in patients with deep overbite relapse.

Although few authors (Cole, 1948; Hernandez, 1969) determined that extraction of teeth would lessen the stability of post-treatment overbite stability, the majority of authors (Schudy, 1963; Simons, 1971; Hechter, 1976, Burstone, 1977) reflect the conclusions of Magill (1960) that proper diagnosis and mechanotherapy rule out the effects of extraction of teeth as a contraindication to overbite correction.

2. Effects of Post-treatment Facial Growth on Overbite Stability

Riedel (1975) had stated that deep overbites treated to an edge to edge relationship will probably change. These changes are in response to post-treatment growth direction changes. If such growth changes are in a vertical dimension, the overbite will probably be maintained. If horizontal growth prevails, the overbite may be subject to post-treatment relapse.

Dempsey (1974) recently confirmed this in his cephalometric study of 25 Caucasoid patients exhibiting either Angle Class I or Class II malocclusions. No age, sex or group breakdown was listed. He concluded that overbite was influenced by mandibular growth that forced the lower incisors against the upper incisors which in turn caused a subsequent increase in the interincisal angle.

In a cephalometric study of post-treatment craniofacial growth in 74 Caucasoid children, Schudy (1974) postulated that a decrease in the vertical growth of the condyle rather than a horizontal acceleration of condylar growth was probably the source of increases in overbite and mandibular incisor crowding. Some of his conclusions were as follows:

(1) condylar growth during the terminal phase of jaw growth proceeds in a predominantly vertical direction;

(2) typical growth shows a decrease in ANB, gonial angle, SN-MP, SN-occlusal plane;

(3) the mandible moves more forward than the maxilla in this period;

(4) the lower incisor change tends to be a vertical response;

(5) post-treatment mandibular rotation and lingual movement of the mandibular incisors are critical factors in the aetiology of post-treatment arch length reduction.

Long (1976) studied 19 patients with metallic implants (12 of whom were from Willbank's 1975 study) in order to assess overbite changes. Reduction of overbite at the time of debanding was 49 percent of the original in the adult group (8) and at 2 years post-treatment (i.e., retention) only 2 percent of the overbite relapsed more for a net correction of 47 percent of the original. In the growing children group (11), a reduction of 45 percent occurred during treatment and after retention, an additional 7 percent more relapsed for a net correction of 38 percent at the end of the retention period. Long concluded that "favourable" growth aided in the maintenance of overbite correction.

Favourable growth would probably imply as Reidel (1975) mentioned growth in a vertical plane. The results of growth studies outlined by Bjork and Skieller (1972), Gasson (1976) and Lavergne (1976) have shown that "growth rotations" of the mandible and the maxilla may affect overbite. No doubt the principles of these growth rotations can be applied to results seen in retention and post-retention changes.

Summary of the Literature Review

It is apparent from this literature review that the aetiologic factors of overbite, and the orthodontic mechanotherapy used for its correction, are not as readily agreed upon as the diagnosis of dental overbite. Orthodontists in the 1930's described the aetiology of overbite from a clinical viewpoint. Vertical relations of the teeth (Strang, 1934) and skeletal relationships (Mershon, 1937) were considered in part or wholly responsible for overbites.

With the advent of cephalometrics and cephalometric studies of the growing face (Broadbent, 1937), emphasis on the aetiology of overbite shifted from purely a clinical assessment to that of assessing the relationship of the growing skeletal components of the face. Analysis of skeletal and dental patterns led to various theories regarding the aetiology and correction of overbite. Growth, or lack of growth, of the mandible (Diamond, 1944), and lower face height (Wylie, 1946) were deemed important aetiologic factors at the time. Later studies, however, have shown that these factors and others had less input than originally determined (Fleming, 1961; Mills, 1973).

In the last two decades, emphasis on overbite had become somewhat more clinical as orthodontists strived to analyze which type of mechanotherapy produced the most satisfactory stable results. Such factors as maxillary and mandibular molar vertical heights (Schudy, 1968; Burstone, 1977), interincisal angle (Schudy, 1963; Dempsey, 1974) and maxillary and mandibular incisor vertical heights (Popovich, 1955; Begg, 1977) have been discussed as aetiologic factors and treatment should be directed at these specific parameters in order to ensure successful overbite correction.

Some studies have examined these and other so called aetiologic factors and found no relationship. Ludwig (1967) and Simons (1971) could find no relation of post-treatment stability of overbite correction and the interincisal angle. Simons (1971) and Menzies (1975) found that in order to correct overbite increasing the vertical heights of the molars has been more stable than incisor intrusion.

Post-treatment growth may influence the correction of deep overbite. Vertical growth of the jaws according to Schudy (1968) and Reidel (1975) are favourable while horizontal growth of the mandible has been found to cause an increase in post-treatment overbite (Dempsey, 1974).

Overbite has been referred as a distinct entity in itself (Mershon, 1937). However, this author feels that in the majority of situations, overbite cannot be classified as such. Based on the review of the literature, no single aetiologic factor can be ascribed to overbite in all cases. Sagittal and vertical jaw relationships, tooth size discrepancies (i.e., Bolton, 1958), tooth size - arch size discrepancies, and the role of the musculature and soft tissues of the craniofacial complex, no doubt, all play some role in the aetiology of overbite. Based on anthropologic observations, one may also consider the role of the changing environment and how it, in turn, has influenced the masticatory apparatus (Keith, 1925; Moore and Lavelle, 1974).

Just as the aetiologic factors are multifactorial so too are the causes for post-treatment change in overbite. Much information has yet to by synthesized regarding the effect of the "soft tissues" of the craniofacial complex, the "forces" of occlusion and post-treatment growth.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

Composition of the Sample

The sample was comprised of eighty-seven Caucasoids selected from the completed files at the University of Manitoba Graduate Orthodontic Clinic. Description of the subjects based on Angle classification and type of treatment (extraction or non-extraction) is found in Table I. Breakdown of the sample based on type of treatment and extraction sites is found in Table II.

Due to the lack of an adequate sample size, Angle Class III patients were omitted from this study. As well, any surgical-orthodontic, cleft lip and/or palate cases, or patients with any craniofacial syndromes or gross skeletal deformities were eliminated from this study. "Open-bite" cases were also omitted due to insufficient numbers.

The pre-treatment age of the sample ranged from 8.5 years to 20.3 years. Means and standard deviations of ages for each Angle class, sex, and stage of study, is found in Table III. Means, standard deviations and ranges of ages by Angle class, type of treatment (extraction or non-extraction) and stage is found in Table XXII (Appendix I).

Each patient's completed file contained 4 serial cephalometric radiographs which were used for analysis. They were labelled as follows:

1) "A" - pre-treatment

2) "B" - immediate post-treatment (debanding)

Table I

Summary of Subjects Based on Type of Treatment, Angle Classification and Sex

Nonextraction			Extraction		Total
Angle classification	Male	Female	Male	Female	
Class I	7	1	3	18	29
Class II Division 1	7	11	10	18	46
Class II Division 2	3	5	2	2	12
Total	17	17	15	38	87

Table II

Summary of Subjects Based on Type of Treatment

I.	Non-extraction	34	34
II.	Extraction		
	1) Maxillary and mandibular first bicuspids	36	
	2) Maxillary first bicuspids	9	
	3) Maxillary first bicuspids, mandibular second bicuspids	4	
	4) Maxillary and mandibular second bicuspids	1	
	5) Maxillary second bicuspids and mandibular	1	
	6) Maxillary lateral incisors and mandibular second bicuspids	2	
			53
	Total		

Table III

Means and Standard Deviations of Ages for the Subjects in this Study

ANGLE CLASSIFICATION	SEX	NUMBER	AGES AT STAGES OF TREATMENT			
			A	B	C	D
CLASS I	FEMALES	19	13.2 ± 1.6YR	15.2 ± 1.7YR	17.0 ± 1.7YR	19.3 ± 1.9YR
	MALES	10	12.5 ± 1.7YR	15.1 ± 1.1YR	16.5 ± 1.0YR	18.6 ± 1.0YR
CLASS II DIVISION 1	FEMALES	29	12.9 ± 1.8YR	15.0 ± 1.7YR	16.6 ± 1.9YR	18.8 ± 1.9YR
	MALES	17	12.5 ± 2.8YR	15.4 ± 2.9YR	17.0 ± 2.8YR	19.3 ± 2.6YR
CLASS II DIVISION 2	FEMALES	7	13.0 ± 2.3YR	15.1 ± 2.8YR	16.5 ± 2.7YR	18.7 ± 2.9YR
	MALES	5	13.3 ± 0.7YR	15.0 ± 1.2YR	16.2 ± 1.2YR	18.7 ± 0.7YR
TOTAL	55 FEMALES + 32 MALES = 87					

3) "C" - immediate post-retention

4) "D" - two or more years post-retention

The mean duration of treatment (stages A to B) for all patients was 2.2 ± 1.1 year. Examination of treatment periods for each of the Angle classes and type of treatment is shown in Table IV. The longer treatment period of both Class II Division I groups may be due to the fact that these patients were often started with extraoral traction during the initial portion of the treatment period. The retention period (stages B to C) for all patients was 1.9 ± 1.1 years. This period covered the time period from debanding and placement of retainers to removal of the last retainer. The post-retention period (stages C to D) for all patients was 2.7 ± 1.0 years.

Lateral cephalometric radiographs were obtained from the files of these eighty-seven completed cases. The radiographs had been taken with the now conventional technique pioneered by Broadbent (1931). A Broadbent-Bolton cephalometer had been used on twenty-four subjects who were the initial patients treated at this institution. A Moss Cephalometrix* cephalometer was used on the remaining sixty-three patients. The Moss Cephalometer had an approximate focal point to film distance of 152.4 centimeters while the Broadbent-Bolton cephalometer had a focal point film distance of 167.6 centimeters. Magnification factors for each machine had been previously established (Frostad, 1969)

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* Moss Corporation - Chicago, Illinois, U.S.A.

Table IV

Means and Standard Deviations in Years of Duration of Treatment (A to B), Retention (B to C) and Post-Retention (C to D) Stages

I. Angle Class I Non-Extraction		N* = 8
Treatment	1.9 ± 0.9 yr.	
Retention	1.6 ± 1.1 yr.	
Post-Retention	2.1 ± 0.6 yr.	
II. Angle Class I Extraction		N = 21
Treatment	2.1 ± 1.3 yr.	
Retention	1.8 ± 1.4 yr.	
Post-Retention	3.6 ± 2.0 yr.	
III. Angle Class II Division 1 Non-Extraction		N = 18
Treatment	2.8 ± 1.6 yr.	
Retention	1.8 ± 1.1 yr.	
Post-Retention	2.7 ± 1.2 yr.	
IV. Angle Class II Division 1 Extraction		N = 28
Treatment	2.7 ± 1.8 yr.	
Retention	2.3 ± 1.7 yr.	
Post-Retention	3.6 ± 1.1 yr.	
V. Angle Class II Division 2 Non-Extraction		N = 8
Treatment	1.8 ± 0.5 yr.	
Retention	2.1 ± 0.6 yr.	
Post-Retention	2.2 ± 0.5 yr.	
VI. Angle Class II Division 2 Extraction		N = 4
Treatment	1.9 ± 0.5 yr.	
Retention	1.9 ± 0.8 yr.	
Post-Retention	2.5 ± 0.6 yr.	
VII. All Subjects		N = 87
Treatment	2.2 ± 1.1 yr.	
Retention	1.9 ± 1.1 yr.	
Post-Retention	2.7 ± 1.0 yr.	

* Where N = Number of subjects

and recently substantiated (Moir, 1978). The magnification was determined to be 7 percent on the Broadbent-Bolton cephalometer and 9 percent on the Moss Cephalometrix cephalometer. Appropriate correction for the two magnifications were performed during the process of analysis (Chebib et al, 1976).

Selection of Landmarks

Using the definitions previously described by Cleall and Chebib (1971), 33 landmarks were defined. These landmarks are illustrated in Figure 1 and a detailed description of these landmarks is found in the Appendix II.

A teletype connected to a Ruscom Logistics strip chart digitizer* was used to enter the "x" and "y" coordinates for each radiograph in a set sequence into the University of Manitoba computer system (IBM 370-68). Since the cephalometric radiographs, despite precautions, were taken at varying orientations and elevations, they were transformed to a standard orientation using the technique described by Cleall and Chebib (1971). This entailed the transformation of the landmarks of each individual's radiograph to standardized coordinates based on a common set of axes. These axes were predefined by a point of origin (#2 - sella) and a directional point (#4 - nasion) (Figure 1) common to all radiographs. The axes for each radiograph were shifted to the point of origin (sella) and rotated around it so the positive direction of the "x" axis passed through nasion. From the

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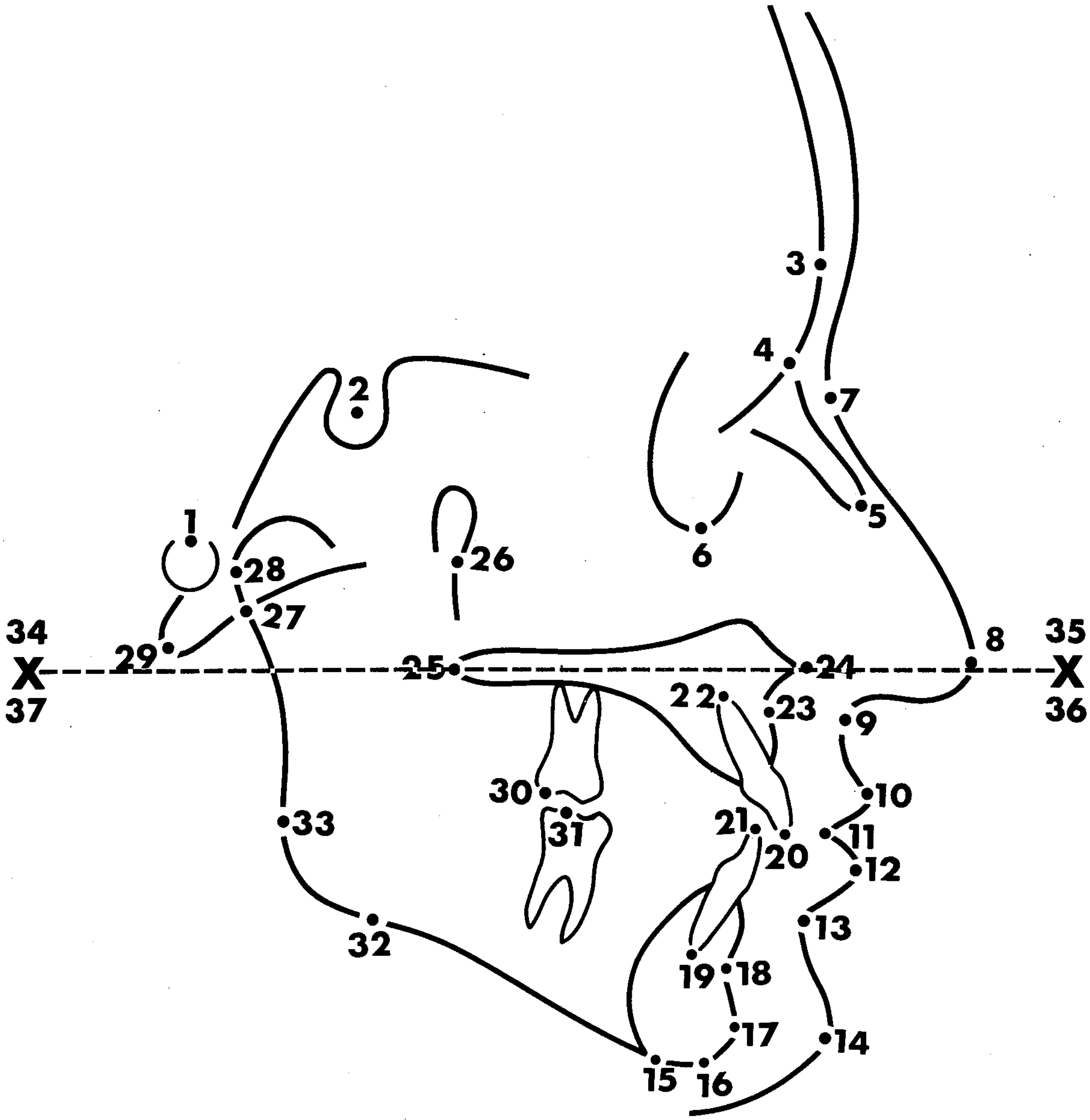
* Ruscom Logics Limited - Rexdale, Ontario, Canada

Figure 1

Cephalometric landmarks after Cleall and Chebib (1971)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standardized coordinates on each radiograph, the linear and angular measurements used in this study were computed and the output recorded on punch cards. These linear and angular measurements were subsequently subjected to further analyses. All linear measurements were recorded in millimeters (mm.) and all angular measurements were recorded in degrees (^{o}).

Cephalometric Analysis

A cephalometric radiographic analysis was used to evaluate, both quantitatively and qualitatively, the morphologic configuration, developmental and/or treatment changes of the dentofacial complex. A total of 51 measurements were computed from each radiograph. These measurements consisted of 31 skeletal variables (14 linear and 17 angular - see Figures 2 and 3) and 20 dental variables (13 linear and 7 angular - see Figures 4, 5 and 6). A detailed description of these 51 measurements is found in Appendix III.

It may be noted from the lists of these variables that several cephalometric planes have been employed in this study (Appendix II). This is largely because assessment of the craniofacial skeleton is frequently compromised by the variability both between and within individuals. Furthermore, the craniofacial skeleton can never be assumed to be in a "steady state" with changes occurring adolescence and old age (Lavelle, 1977). The selection of an "ideal plane" is therefore impossible and one's only recourse is to choose those points or that plane which best describes the particular area of interest.

As dental models were not used in this study, a suitable

Figure 2

Linear skeletal measurements

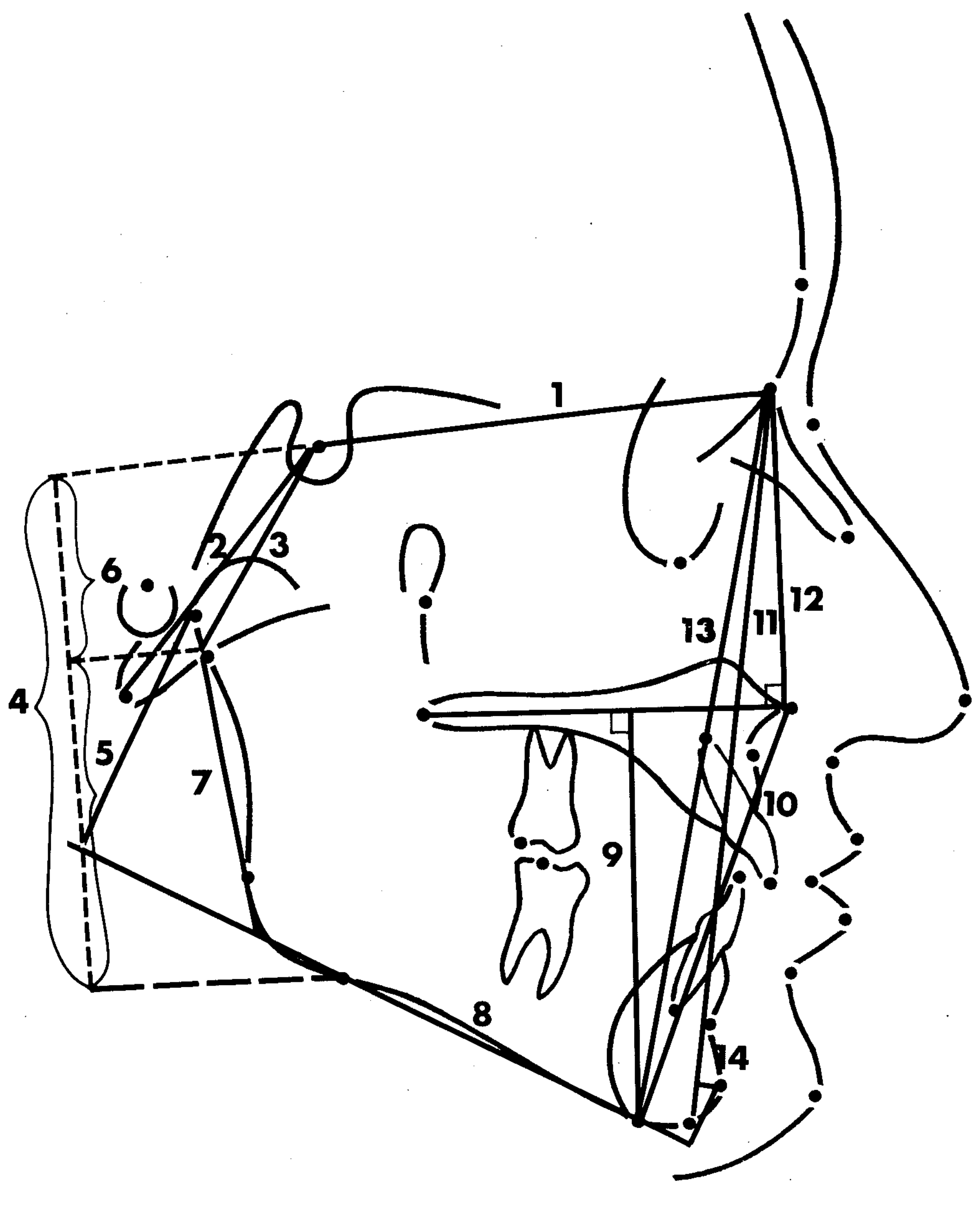
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Figure 3

Angular skeletal measurements

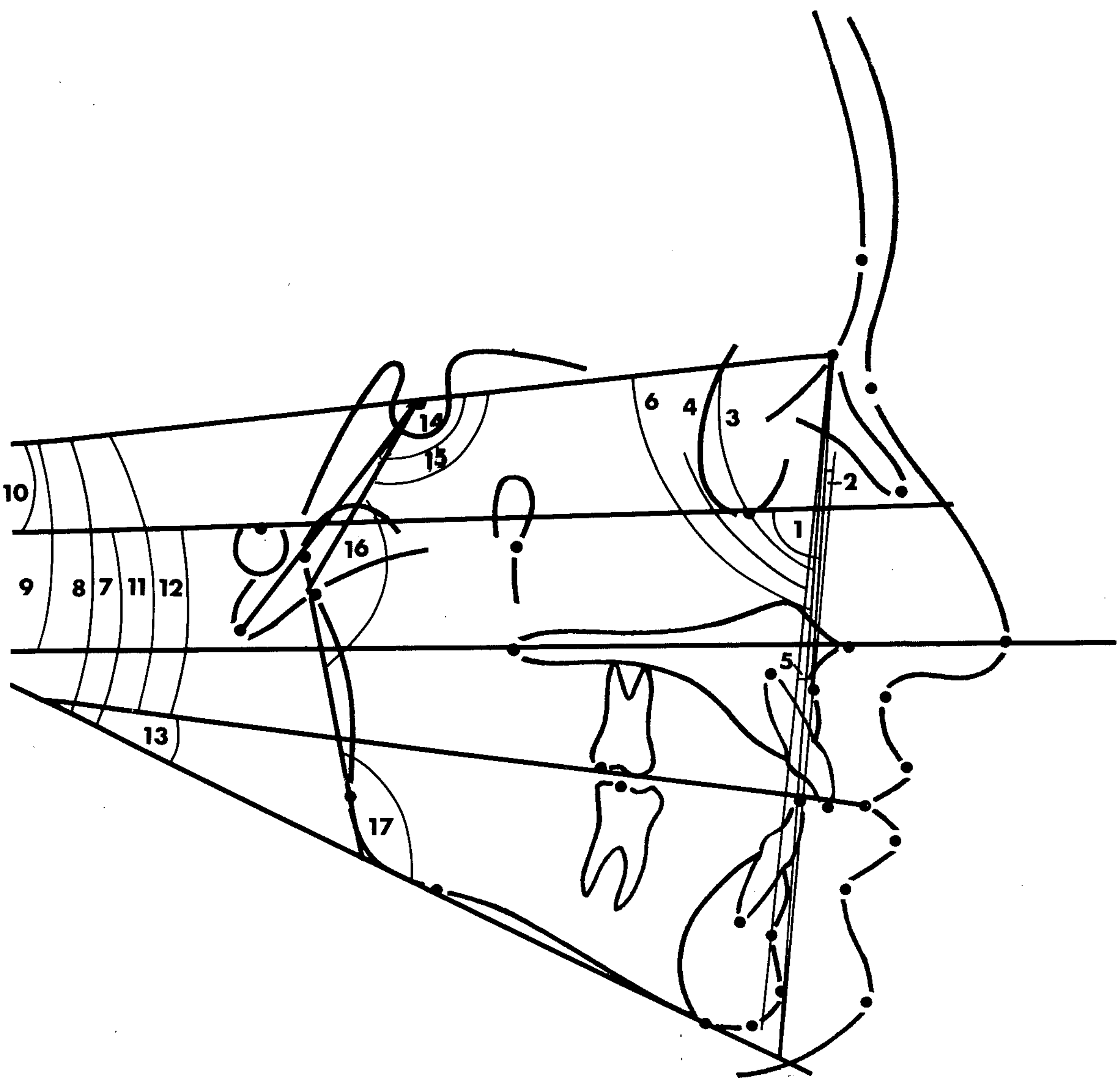

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Figure 4

Linear dental measurements (maxillary arch)

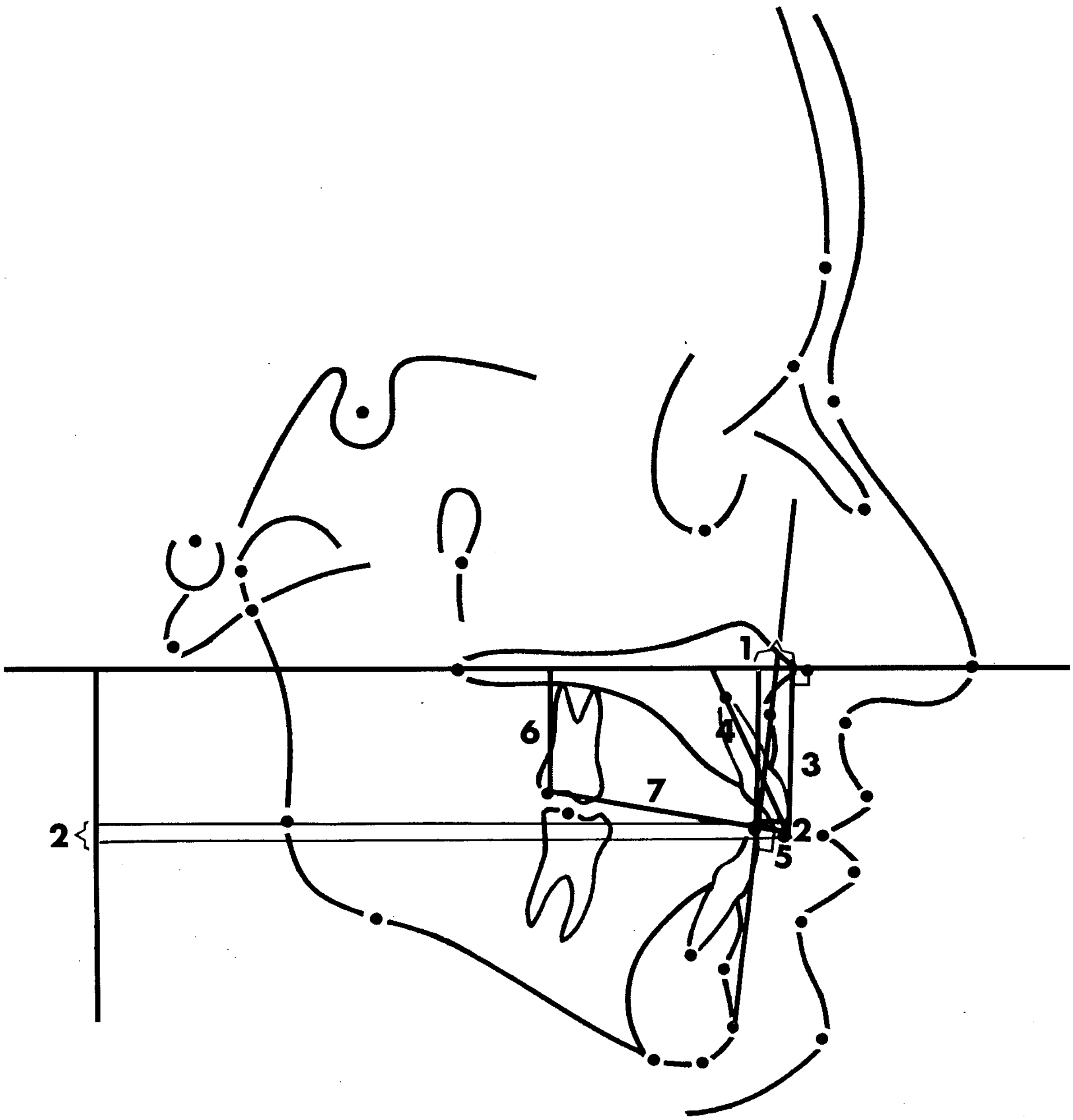
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Figure 5

Linear dental measurements (mandibular arch)

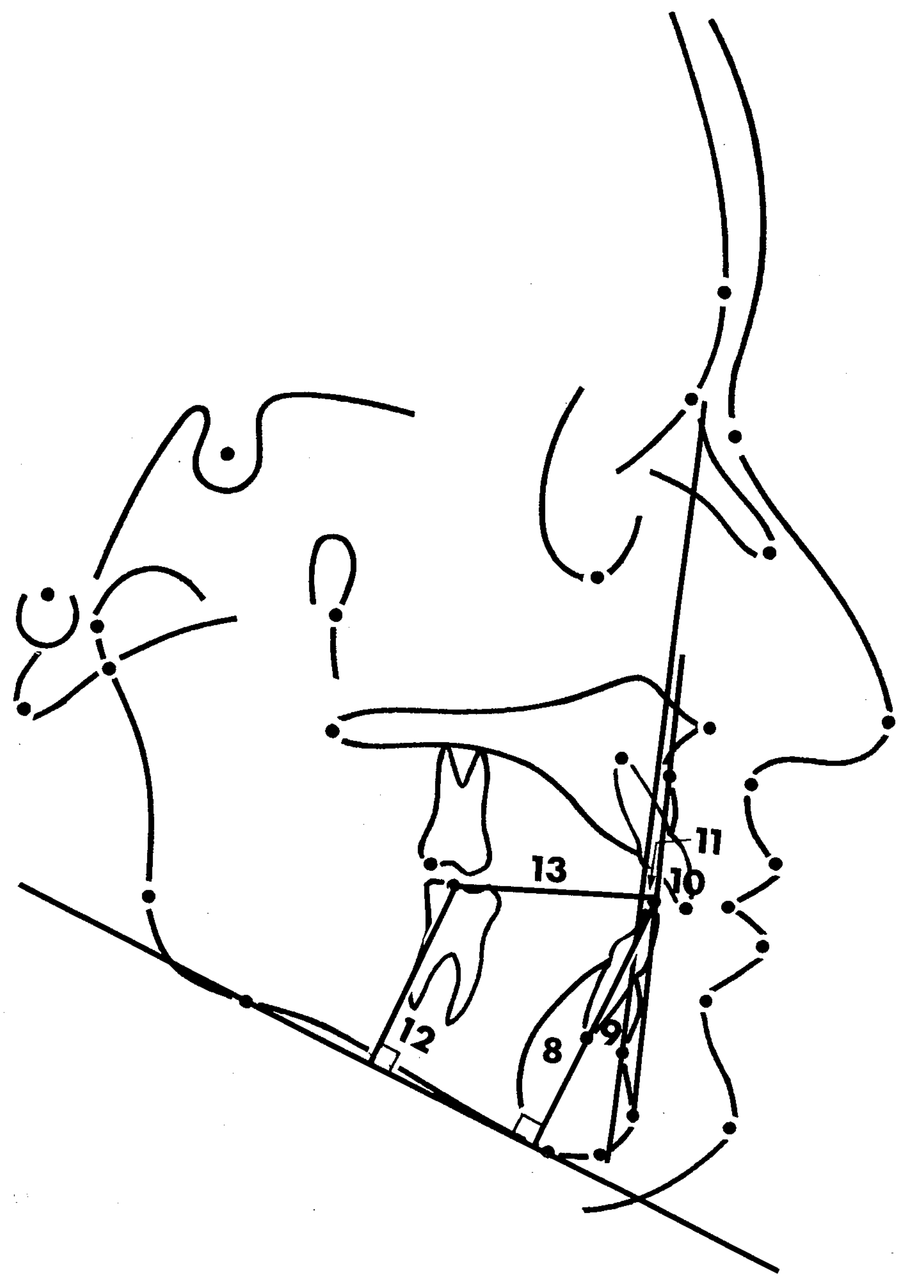
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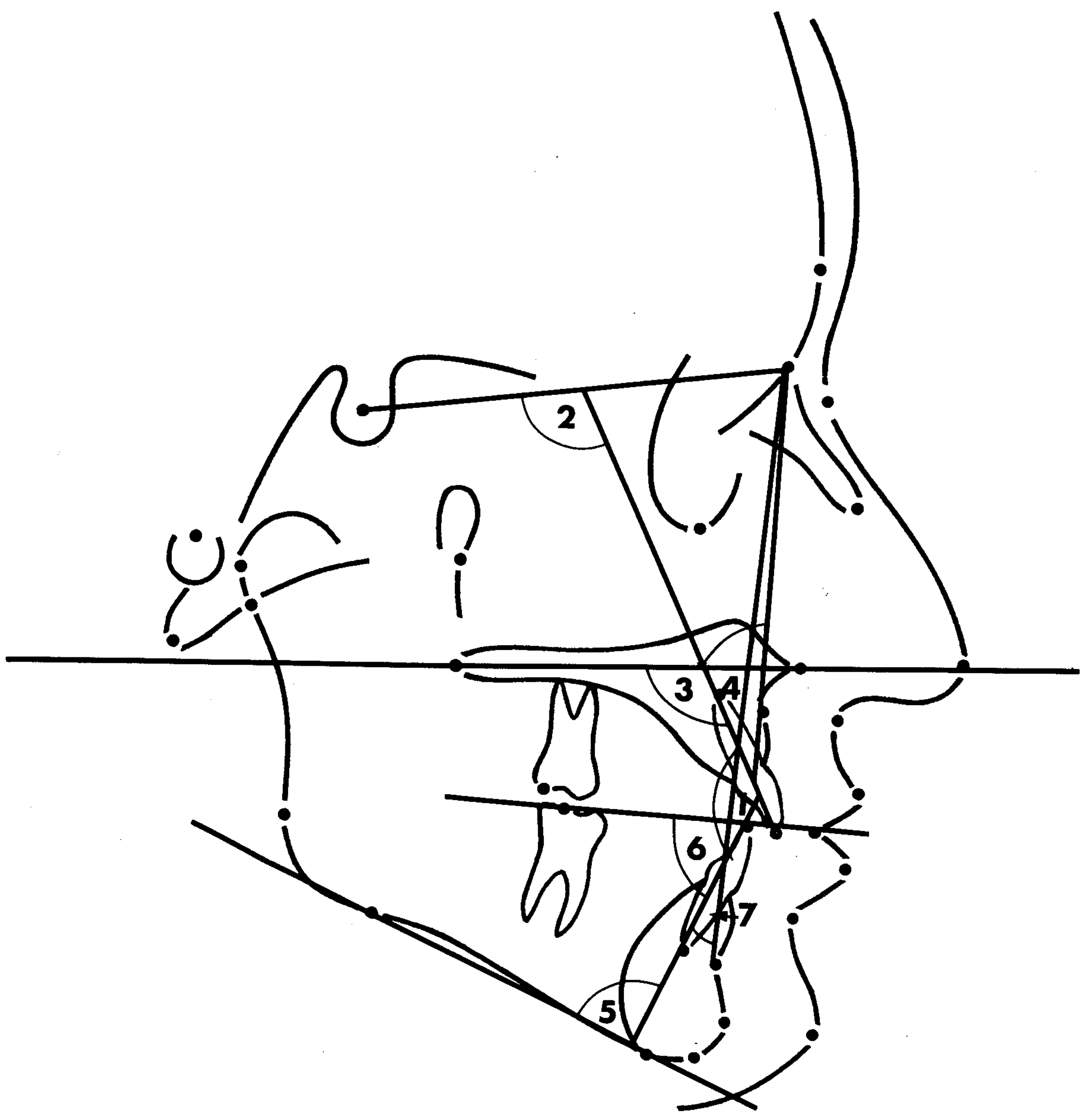
Figure 6

Angular dental measurements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cephalometric reference plane to measure overbite was desirable. The occlusal plane from the cusp tips of the molars to the incisal edge of the upper central incisor was used by Bjork (1953) and Simons (1971), while Dempsey (1974) bisected the vertical overlap of the upper and lower incisors to measure overbite. Magill (1960) reports that although this method does give a suitable assessment of overbite, the occlusal plane is subject to changes in its cant and these changes will affect anterior overbite calculations. Popovich (1953) and Ludwig (1966, 1967) used the facial plane (nasion to pogonion) to measure overbite. Despite the fact that the facial plane adds to the simplicity of the measuring process, any changes in the position of pogonion can alter the overbite measurment.

Other investigators favoured the palatal plane. Magill (1960) suggested that the palatal plane was just as acceptable if not better than using the occlusal plane. Brodie (1953) and Ricketts (1960) determined that during growth, palatal plane, as represented by a line joining anterior and posterior nasal spine, was stable and changed little in relation to other planes used. Simons (1971) confirmed that the palatal plane descended in a parallel fashion to Frankfort Horizontal. Ricketts did find, however, that the palatal plane may be altered by prolonged heavy Class II mechanics or orthopaedic forces and as a result, the palatal plane may be tipped down in the anterior region. The changes in palatal plane were less than those of the occlusal plane. Gasson and Lavergne (1977) report the maxilla as measured by the palatal plane rotates during growth and that these subsequent sagittal and vertical rotations may influence the development of a malocclusion. In spite of changes due to treatment or growth, the palatal plane yields a larger numerical dimension as compared to other planes (Magill, 1960; Brugg, 1973) and the stability of this plane is greater than other reference planes previously reported in the literature (Ricketts, 1960). Ignoring the changes in palatal plane may tend to obscure changes in the anterior dental units as these are intimately related. Based on the above considerations, the palatal plane was chosen to measure overbite.

Using the on-line computer program "Cephalometric Records Analysis Program" (Chebib et al, 1976) localized analyses have been designed for the assessment of tooth movement during treatment and/or growth. A tracing of the maxillary and mandibular outlines, the pterygo-maxillary fissure and any cancellous spaces in the palatal area, and including the inferior dental canal and symphyseal details is made. The mandibular tracing is based on the studies of Bjork (1969). The tooth positions are omitted on the tracing. A palatal plane is drawn through anterior nasal spine (ANS) and posterior nasal spine (PNS) on the pre-treatment radiograph template and two pinholes are made through the tracing and the original radiograph. These points are now a fixed distance apart and remain so through the ensuing serial radiographs. Using a best fit system on the maxillary and mandibular outlines, these "transfer points" are transferred to subsequent radiographs and become landmarks 34, 35, 36 and 37 (Figure 1). The computer has been programmed to superimpose on these points of registration and permits changes in relationship of the dental units to be assessed in the maxilla and the mandible. For the maxilla analysis the points of origin was point 34 and direction was point 35; for the mandible analysis point 37 was the origin and point 36 was the direction.

Error of Measurement

To determine overall errors, 30 charts were randomly selected from the 87 patients in this study. One of the four lateral cephalometric radiographs in each chart was randomly chosen and the 37 landmarks were redigitized on two more separate occasions. To estimate measurement error, fifteen commonly used orthodontic variables were calculated from each of the triplicate sets of coordinates obtained from each radiograph. These variables are listed in Table V.

The measurement error included the calculation of the expected mean error (e), standard deviation of measurement error(s), and the maximum error (e_p) associated with 99 percent of the values as outlined by Chebib and Burdick (1973) according to the following formulas:

$$s = \sqrt{\frac{\Sigma\left[\Sigma\ (x-\bar{x})^2\right]}{\Sigma\ (n-1)}}\ , \quad df = \Sigma\ (n-1)$$

Where n is the number of times each radiograph was digitized for determination of the measurement error and in this case n = 3;

$$\bar{e} = \pm\sqrt{\frac{2}{\pi}}\ s = \pm\ .7979s$$

$$e_p = \pm t(99\%, df)\ s$$

Where t is the student's t value for "df" degrees of freedom and probability "p" (99%).

Table V

Expected Mean Error ($\bar{e}$), Standard Deviation of Measurement Error(s), 99% Maximum Error, 99% Maximum Error for k Subjects for 15 Cephalometric Skeletal and Dental Variables

Variable	Expected Mean Error	Standard Deviation of Error (±)	99% Maximum Error (±)	99% Maximum Error Associated with a Mean of 25 Subjects (±)
1. Facial Plane	0.69°	0.87°	2.31°	0.46°
2. Angle of Convexity	1.06°	1.33°	3.53°	0.70°
3. SNA	0.82°	1.03°	2.74°	0.54°
4. SNB	0.67°	0.84°	2.24°	0.45°
5. ANB	0.47°	0.59°	1.57°	0.31°
6. Mandibular Plane (FH)	0.79°	0.96°	2.65°	0.52°
7. Interincisal Angle	1.58°	1.98°	5.26°	1.15°
8. UI-SN	1.37°	1.72°	4.58°	0.91°
9. LI-MP	1.19°	1.50°	3.98°	0.79°
10. UI-AP	0.28 mm	0.35 mm	0.92 mm	0.18 mm
11. LI-AP	0.32 mm	0.40 mm	1.06 mm	0.20 mm
12. LI-NB	0.27 mm	0.31 mm	0.82 mm	0.16 mm
13. P-NB (Chin)	0.20 mm	0.25 mm	0.67 mm	0.13 mm
14. Overjet	0.26 mm	0.32 mm	0.86 mm	0.17 mm
15. Overbite	0.30 mm	0.37 mm	0.98 mm	0.19 mm

The maximum error associated with 99 percent of the measurements is listed in Table V. In 99 percent of the measurements the error associated with a single value will be less than the reported error and only in rare occasions (1 percent) will the measurement error exceed these values.

The errors of measurement associated with a mean of "k" subjects(s') may be calculated as follows:

$$s' = \frac{s}{k}$$

and the corresponding maximum error will be:

$$\pm t(99\%,df)\ s'$$

The maximum errors associated with a mean of, for example, 25 subjects have been computed and have been listed in the last column of Table V.

It can be seen from the results listed in Table IV that the maximum error for the angular variables for any one subject ranged from 1.57 degrees (angle ANB) to 5.26 degrees (interincisal angle) and for the linear distances from 0.67 mm (P-NB) to 1.05 mm (LI-AP). For a mean of 25 subjects the maximum errors for the angular measurements ranged from 0.31° (angle ANB) to 1.15° (interincisal angle). For the linear measurements the maximum errors for 25 subjects ranged from 0.13 mm (P-NB) to 0.20 mm (LI-AP). The largest errors, which were angular measures were associated with the incisor teeth and this is no doubt due to the difficulty in locating the apices, especially those of the lower incisors.

Statistical Analyses

A. Correlation Analysis

The relationship of overbite with each of 46 measurements (22 angular and 24 linear - see Table VIII - Results) was examined through the calculation of a Pearson product moment correlation coefficient. As the sample included a large degree of variability with respect to occlusion and sex differences, the "global" correlations may not have been representative of the true relationships studied. The correlation coefficients therefore were calculated separately within each of the 6 occlusion-sex subgroups (Table III) and then "pooled" according to the method of Burdick and Chebib (1972).

This method assumes that the correlations within the groups are equal but the groups themselves may be different. The intra-group relationship may thus be "pooled" (i.e., averaged in such a way that the group mean levels are brought to the same levels) to obtain a general intra-group relationship.

The "pooled" correlations were calculated for each variable for each of the 4 records in the study. The degrees of freedom for each of the subgroups was n-2 and thus for the "pooled" correlations for each stage (A,B,C and D) was N-12.

B. Analysis of Variance

In order to describe the changes of the variables over the 4 stages and compare these changes between the groups a factorial analysis of variance was employed. The sample breakdown was based on the type of treatment (extraction versus non-extraction and Angle's classification (Table I). The sexes were combined due to small numbers in each group.

The factors, therefore, were:

Treatment at 2 levels: extraction vs. non-extraction

Angle Class at 3 levels: Class I vs. Class II Div. 1 vs. Class II Div. 2

Stage of treatment at 4 levels: A vs. B vs. C vs. D

As one of the factors (stage) varies across subjects (correlated levels) while the other two (treatment and class) vary between subjects (independent levels) the 2 x 3 x 4 factorial design was analyzed by a mixed analysis of variance as described by Becker and Chebib (1969). The mixed analysis of variance was performed on each of the variables listed in Tables X, XII, XV and XVII.

The 347 degrees of freedom available from the 87 subjects at the 4 stages were allocated as shown in Table VI. All mean squares of main effects and interactions were tested for significance by the variance "F" tables. For the sake of expediency, the mean squares and levels of significance for the variables overbite, overjet and inter-incisal angle were shown (Table X). All other variables subjected to the mixed analysis of variance show only the levels of significance (Table XII, XV and XVII).

In order to further examine the effect of treatment for the correction of overbite on individuals with varying initial overbites in this sample, the 87 subjects were regrouped on the basis of the initial vertical depth of overbite (stage A). Thus, this disregarded Angle's

Table VI

ALLOCATION OF DEGREES OF FREEDOM FOR MIXED ANALYSIS OF VARIANCE (87 SUBJECTS)

Sources of Variation	Degrees of Freedom
Treatment	1
Angle Class	2
Treatment × Class	2
BETWEEN SUBJECTS ERROR	81
Stage	3
Treatment × Stage	3
Class × Stage	6
Treatment × Class × Stage	6
WITHIN SUBJECTS ERROR	243
TOTAL	347

Table VII

Summary of 87 Subjects Based on Depth of Overbite, Type of Treatment and Sex.

Depth of Overbite	Nonextraction		Extraction		
	Male	Female	Male	Female	Total
Shallow (–1.0 to 2.5 mm)	4	2	2	10	18
Moderate (2.6 to 5.5 mm)	7	11	2	17	37
Deep (5.6 to 10.0 mm)	6	4	11	11	32
Total	17	17	15	38	87

classification. Three categories of overbite depth were arbitrarily designated and were similar to those of the studies of Wylie (1946) and Simons (1971). These categories were:

(1) shallow overbite (0.0 to 2.5 mm)

(2) moderate overbite (2.6 to 5.5 mm)

(3) deep overbite (5.6 to 10.0 mm)

Other studies have employed a similar technique of sample structuring but have divided their samples into only two categories, shallow and deep overbites (Richardson, 1969; Dooley, 1973).

The breakdown of the sample based on initial vertical depth of overbite, treatment (extraction vs. non-extraction) and sex, is shown in Table VII). The mixed analysis of variance was applied only to the variable overbite. The design of this test remained a 2 x 3 x 4 mixed factorial design and the degrees of freedom remained the same as the previous analysis of variance, the only change was the sources of variation:

1) Treatment at 2 levels: extraction vs. non-extraction

2) Depth of overbite at 3 levels: shallow vs. moderate vs. deep

3) Stages at 4 levels: A vs. B vs. C vs. D

Polygonal Profiles

For visual non-quantitative comparisons, mean coordinates obtained from the statistical data were used to construct facial polygons using a specially designed computer plotting program*. The purpose of the polygons was to compare the differences in the facial skeleton of each Angle class at stage A (pre-treatment) and observe the changes due to growth and/or orthodontic treatment.

The polygon consisted of points 4, 2, 27, 33, 32, 15, 16, 17, 19, 21, 20, 22, 24, 25 (see Figure 7). Incisor proclination and occlusal plane (points 31 to 21) were represented to depict dental factors.

Moore (1971) has suggested that maximum superimposition of the sphenoid plane, ethmoid plane and the inner shadow of the contour of the middle cranial fossae is suitable for evaluating cephalometric changes within a subjects series. However, this study was designed to measure not only intrasubject changes, but intersubject changes, hence the more standard cephalometric plane sella-nasion was employed for orientation of skeletal changes. It must be remembered that when quantifying the changing relationships of the teeth or craniofacial structures with angular or linear measurements, such changes are relative only to the common point or plane.

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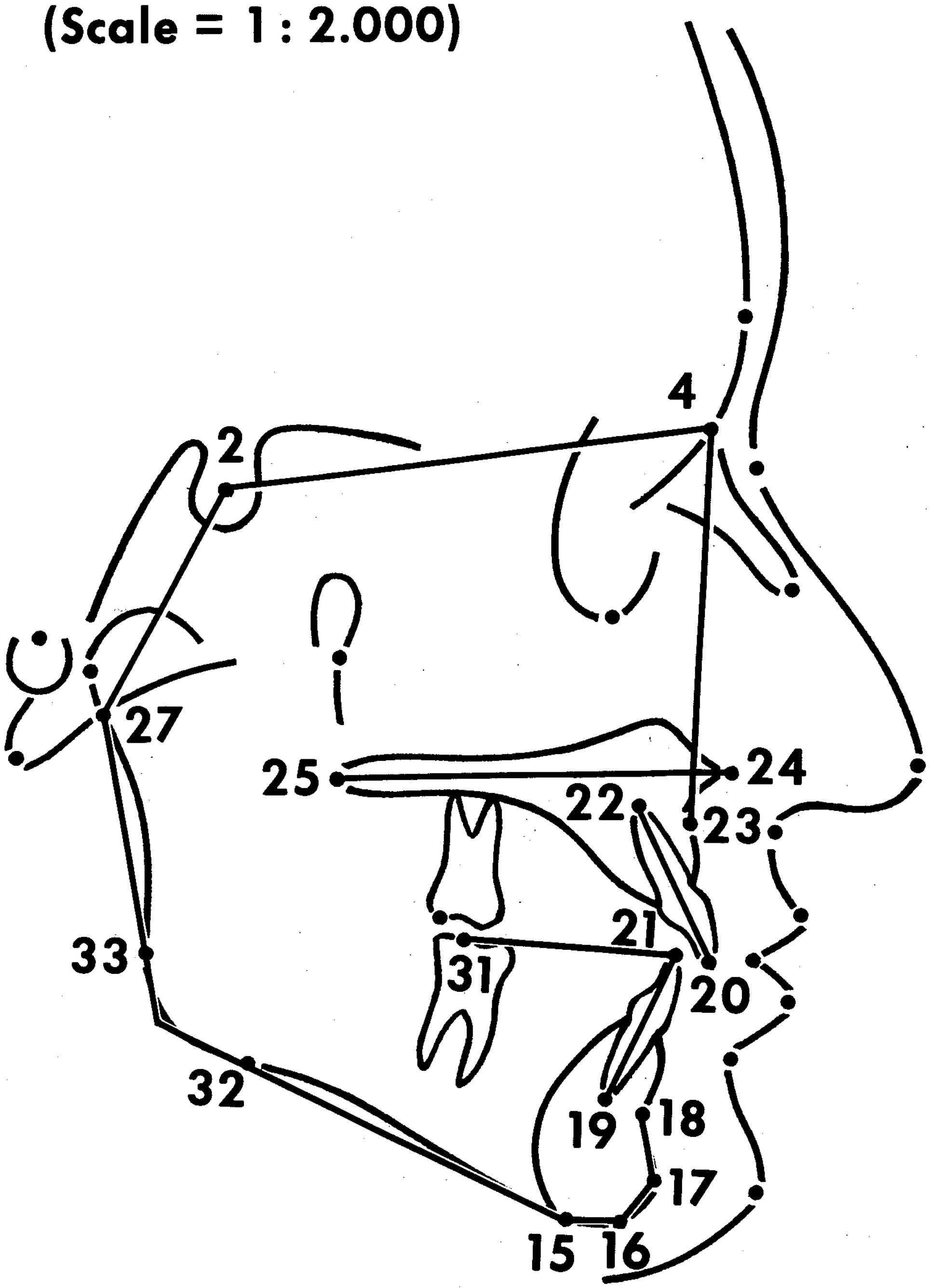
* F. S. Chebib, Biostatistician, Dept. of Preventive Dental Science

Figure 7

Computer drawn cephalometric polygon

CEPHALOMETRIC FACIAL POLYGON

(Scale = 1 : 2.000)



RESULTS

CHAPTER IV

RESULTS

The results are presented in the following sections. The first gives the results of the pooled correlations for the factors associated with overbite. This was based on the study of the 87 subjects grouped according to sex and Angle's classification. No differentiation of treatment methodology was made.

The second section describes the results of the analyses of variances of overbite and other variables associated with overbite. The main effects of Treatment (extraction vs. non-extraction), Class (Class I vs. Class II Division 1 vs. Class II Division 2) and Stage (pre-treatment A, treatment B, retention C, post-retention D) and their interactions were analyzed. The sample was grouped according to type of treatment (extraction or non-extraction) Angle class and the sexes were combined.

The third section describes the mean changes in overbite for the sample based on the type of treatment and Angle class and examines the post-treatment changes in overbite. Comparison was performed on the results of an analysis of variance when the sample was reorganized on the basis of the initial vertical depth of overbite.

The fourth section shows the figures of the computer drawn polygons for each of the Angle classes at stage A. In order to compare each of the groups, transparencies of each class for stage A using a photocopier* were made. As well, transparencies of the computer drawn

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* Xerox 4000

polygons were made for each of the three Angle classes for each of the four stages. These are found in Appendix.

"Pooled" Correlations

Table VIII shows the "pooled" correlation coefficients between overbite and each of the fourty-six variables studied for each of the four stages of treatment. "Pooling" the correlations was an attempt to average the correlations for each of the six subgroups in order to correct for the differences between the subgroups. However, in any one subgroup, a particular variable may have a high degree of association and in another subgroup there may be little or reverse association and the "pooled" correlation being an average, may obscure some "within group" relationships.

The strength (magnitude) of the correlation coefficients are of more importance than their level of significance. On this basis, the ten variables showing the largest correlation with overbite at stage A were examined.

Table IX lists these ten variables and their correlation coefficients as well as their levels of significance. It may be noted from this table that the following six variables became statistically insignificant with overbite during treatment; they are lower incisor to to AP, upper molar perpendicular to palatal plane, anterior lower face height, ANB, anterior total face height and lower molar perpendicular to mandibular plane. With the exception of ANB, all of these variables tended to return to the pre-treatment values. Variables listed in Table IX showed no consistent change between pre-treatment and post-retention stages.

The following variables revealed that the strength of their

TABLE VIII

"Pooled"Correlations - Overbite

Independent Variables	Stages A *df = 75	B df = 75	C df = 75	D df = 75
1. Facial angle	- 0.150	0.114	- 0.111	0.032
2. Angle of convexity	0.187	0.025	0.010	- 0.090
3. SNA	0.117	0.100	0.059	- 0.062
4. SNB	- 0.047	0.063	0.027	- 0.069
5. ANB	0.289	0.085	0.064	0.013
6. Mandibular plane to FH	- 0.085	- 0.177	- 0.034	- 0.178
7. Mandibular plane to SN	- 0.221	- 0.161	- 0.165	- 0.168
8. SNPg	0.007	0.086	0.057	- 0.005
9. Y axis	- 0.064	- 0.149	- 0.019	- 0.188
10. Palatal plane to SN	- 0.012	- 0.125	0.127	0.137
11. Midline cranial base (Na-S-Pa)	- 0.081	0.063	- 0.005	0.125
12. Lateral cranial base (Na-S-Ar)	- 0.068	0.121	0.087	0.035
13. Sella-articulare-gonion	0.034	- 0.147	- 0.238	- 0.222
14. Gonial angle	- 0.154	- 0.093	0.133	0.066
15. Occlusal plane to FH	- 0.277	- 0.412	- 0.166	- 0.346
16. OM angle	0.240	0.288	0.157	0.231
17. Ramus length (Ar to MP)	- 0.177	0.087	0.129	0.059
18. Perp. post. LFH	- 0.015	- 0.070	- 0.038	- 0.137
19. Perp. post. TFH	- 0.183	0.068	0.164	0.034
20. Mandibular length (Wylie)	- 0.130	0.039	- 0.011	- 0.127
21. Chin (Pogonion to NB)	0.171	0.075	0.082	0.224
22. Anterior cranial base (Na-S)	0.134	0.035	0.242	0.159
23. Posterior cranial base (S-Ba)	- 0.050	0.084	- 0.076	- 0.194
24. Post. upper face height (S-Ar)	- 0.051	- 0.015	- 0.004	- 0.149
25. Palatal length (ANS-PNS)	0.044	0.083	0.248	0.171
26. Ant. total face height (Na-Me)	- 0.276	- 0.077	- 0.128	- 0.276
27. Ant. upper face height (Na-ANS)	- 0.031	- 0.139	0.185	0.025
28. Ant. lower face height (ANS-Me)	- 0.315	- 0.040	- 0.208	- 0.034
29. Overjet	0.314	0.413	0.096	0.156
30. Upper incisor perp. to PP	- 0.031	0.197	- 0.011	- 0.106
31. Upper molar perp. to PP	- 0.319	0.043	- 0.206	- 0.288
32. Effective distance UI to PP	- 0.098	0.189	- 0.085	- 0.182
33. Upper incisor to AP	- 0.001	0.120	- 0.255	- 0.246
34. Maxillary arch length	0.177	0.125	- 0.031	- 0.090
35. Effective distance LI to MP	- 0.039	0.161	0.027	- 0.141
36. Lower incisor to AP	- 0.439	- 0.229	- 0.348	- 0.395
37. Lower incisor to NB	- 0.202	- 0.174	- 0.295	- 0.351
38. Lower incisor perp. to MP	- 0.049	0.174	- 0.017	- 0.135
39. Lower molar perp. to MP	- 0.232	0.012	- 0.086	- 0.253
40. Mandibular arch length	- 0.028	- 0.019	- 0.135	- 0.149
41. Interincisal angle	0.185	0.170	0.314	0.372
42. Upper incisor to SN	0.002	- 0.016	- 0.146	- 0.162
43. Upper incisor to NA	- 0.212	- 0.072	- 0.190	- 0.166
44. Lower incisor to NB	0.158	- 0.231	- 0.313	- 0.417
45. Lower incisor to MP	0.029	- 0.109	- 0.150	- 0.191
46. Lower incisor to occlusal plane	0.182	0.066	- 0.060	- 0.056

* df = N-12

association with overbite increased or decreased consistently from the initial stage A (Table VIII). They were interincisal angle, upper incisor to SN (^{o}), lower incisor to NB (^{o}) and lower incisor to mandibular plane (^{o}).

TABLE IX

"Pooled" correlations and levels of significance for variables showing the largest pre-treatment association with overbite

Variable	Stage A	Stage B	Stage C	Stage D
1. Lower incisor to AP	-0.439***	-0.229	-0.348**	-0.395***
2. Upper molar perp. to PP	-0.319**	0.043	-0.206	-0.288*
3. Anterior lower face height	-0.315**	-0.040	-0.208	-0.304**
4. Overjet	0.314**	0.413***	0.096	0.156
5. ANB	0.289*	0.085	0.064	0.013
6. Occlusal plane to FH	-0.277*	-0.412***	-0.166	-0.346**
7. Anterior total face height	-0.276*	-0.077	-0.128	-0.276*
8. OM angle	0.240*	0.288*	0.157	0.231*
9. Lower molar perp. to MP	-0.232*	0.012	-0.086	-0.253*
10. MP to SN	-0.221*	-0.161	-0.165	-0.168

*** $p < 0.001$
** $p < 0.01$
* $p < 0.05$

Analyses of Variance

The mixed factorial analysis of variance estimated the effect of Treatment (extraction vs. non-extraction) in the three Angle classes (Class 1 vs. Class II Division 1 vs. Class II Division 2) over the four stages of the study for each of 32 dental and skeletal measurements listed in Tables X, XII, XV and XVII. The results of these analyses of variances are presented as mean squares and significance levels for all the other variables (Tables XII, XV and XVII).

In order to facilitate presentation of the results of the mixed analysis of variance, the 32 variables will be presented in the following groups:

A. Interincisor relationships (Table X)

B. Maxillary and mandibular dental measurements (Table XII)

C. Angular skeletal measurements (Table XV)

D. Linear skeletal measurements (Table XVII)

An overview of these tables reveals, that although the treatment groups (extraction vs. non-extraction) are significantly different for many of the variables examined, the lack of interaction of Treatment with the other two factors studied (Class and Stage), indicate that initial differences between the two treatment groups or lack of, persist and are not affected by the class and stage, i.e., extraction vs. non-extraction did not play a significant role in the changes of the variables over the four stages.

Many of the variables studied showed significant differences between the Angle classes and also most variables showed significant differences over the four stages. However, in many cases, significant interactions were detected between Class and Stage, indicating that different Angle classes may behave differently over the four stages.

Means, standard errors and levels of significance for the factor Treatment are presented in the Appendix IV (Table XXIII) while those for the other two factors, Class and Stage are presented below.

A. Interincisor relationships

The results for the mixed analysis of variance for the interincisor relationships, overbite, overjet and interincisal angle are presented in Table X. From this table it was noted that the non-extraction and extraction groups differed significantly with respect to overbite and interincisal angle ($p < 0.001$). The extraction category showed the greater overbite and higher interincisal angle (Table XXIII, Appendix).

Further examination of Table X reveals highly significant differences for the factors Class and Stage and the interaction Class x Stage for each of these three variables. Both overbite and overjet were significant at the 0.1 percent level for Class, Stage and Class x Stage. The interincisal angle was significant at the 0.1 percent level for Class and Class x Stage while the factor Stage was significant at the 1 percent level. Corresponding means and standard errors are presented in Table XIa, b and c.

All three variables show that the significant differences present at stage A disappear at stage B (immediate post-treatment) and subsequently return to their pre-treatment values in the post-treatment

TABLE X

Mean Squares and Levels of Significance for Mixed Analysis of Variance for Three Interinicisor Relationships (Treatment - Class - Stage)

		Mean Squares of Variables		
Source of Variation	df+	Overbite	Overjet	Interincisal Angle
Treatment	1	0.6146***	0.0278	5593.3906***
Class	2	0.6792***	0.5219***	3152.4004***
Treatment x Class	2	0.1009	0.0767	518.7730
Between Subjects Error	81	0.0331	0.0358	213.7730
Stage	3	1.2804***	0.7391***	255.3376**
Treatment x Stage	3	0.0034	0.0030	57.9762
Class x Stage	6	0.1374***	0.3170***	958.2231***
Treatment x Class x Stage	6	0.0036	0.0044	24.9331
Within Subjects Error	243	0.0126	0.0161	42.6729

+ degrees of freedom
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

TABLE XI

Effects of Stage and Angle Classification

a) Overbite (mm)

Angle Classification		Stages A	B	C	D	Classes
Class I N = 29	Mean S.E.	2.32 ±0.21	1.35 ±0.21	2.06 ±0.21	2.40 ±0.21	2.03 ±0.17
Class II Div. 1 N = 46	Mean S.E.	5.07 ±0.17	1.82 ±0.17	2.67 ±0.17	3.15 ±0.17	3.18 ±0.13
Class II Div. 2 N = 12	Mean S.E.	6.32 ±0.32	1.84 ±0.32	3.08 ±0.32	3.88 ±0.32	3.78 ±0.26
Stages	Mean S.E.	4.57 ±0.12	1.67 ±0.12	2.60 ±0.12	3.14 ±0.12	3.00 ±0.10

b) Overjet (mm)

Angle Classification		Stages A	B	C	D	Classes
Class I N = 29	Mean S.E.	3.85 ±0.24	2.68 ±0.24	2.96 ±0.24	3.29 ±0.24	3.20 ±0.24
Class II Div. 1 N = 46	Mean S.E.	7.71 ±0.19	2.86 ±0.19	3.14 ±0.19	3.50 ±0.19	4.30 ±0.14
Class II Div. 2 N = 12	Mean S.E.	2.82 ±0.37	2.92 ±0.37	2.70 ±0.37	2.77 ±0.37	2.80 ±0.27
Stages	Mean S.E.	4.80 ±0.14	2.81 ±0.14	2.93 ±0.14	3.19 ±0.14	3.43 ±0.14

c) Interincisal Angle (^{o})

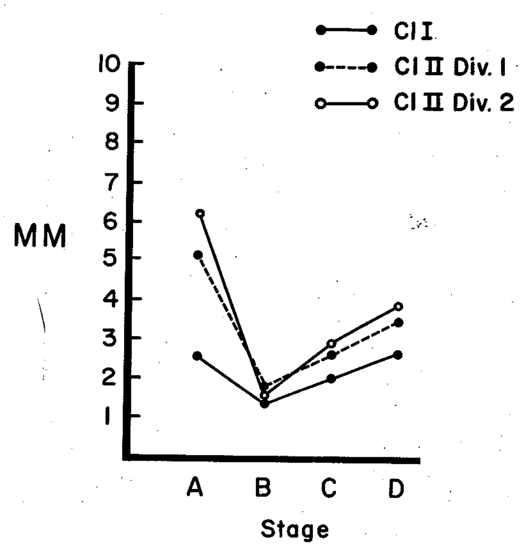
Angle Classification		Stages A	B	C	D	Classes
Class I N = 29	Mean S.E.	125.16 ±1.21	127.60 ±1.21	128.98 ±1.21	128.82 ±1.21	127.63 ±1.36
Class II Div. 1 N = 46	Mean S.E.	121.27 ±0.96	129.19 ±0.96	131.28 ±0.96	130.32 ±0.96	128.01 ±1.08
Class II Div. 2 N = 12	Mean S.E.	150.06 ±1.89	129.45 ±1.89	136.28 ±1.89	137.43 ±1.89	138.31 ±2.11
Stages	Mean S.E.	132.16 ±0.70	128.75 ±0.70	132.18 ±0.70	132.19 ±0.70	131.32 ±0.78

Figure 8. Treatment changes for overbite by stage and class

Figure 9. Treatment changes for overjet by stage and class

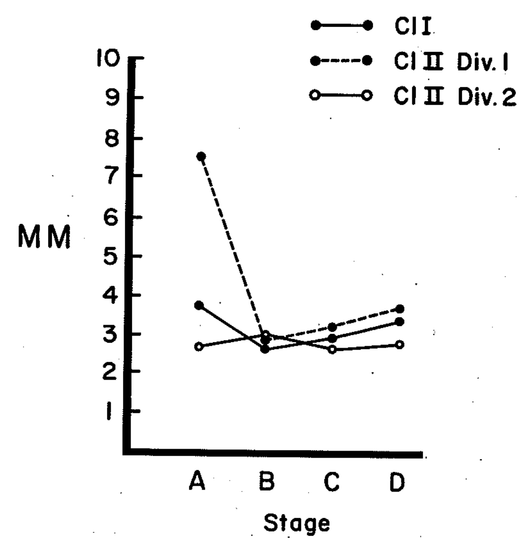
Figure 10. Treatment changes for interincisal angle by stage and class

Figure 8



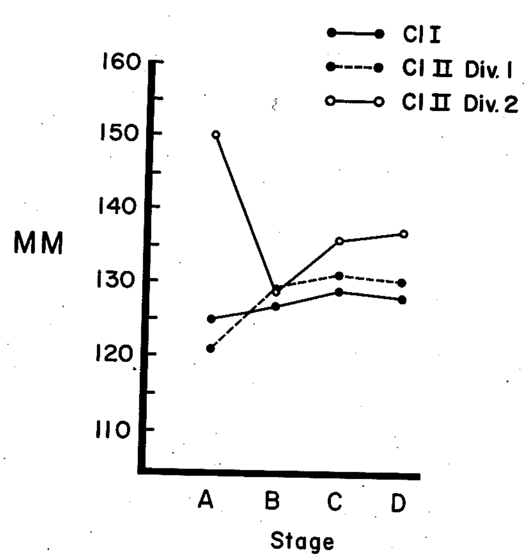
OVERBITE

Figure 9



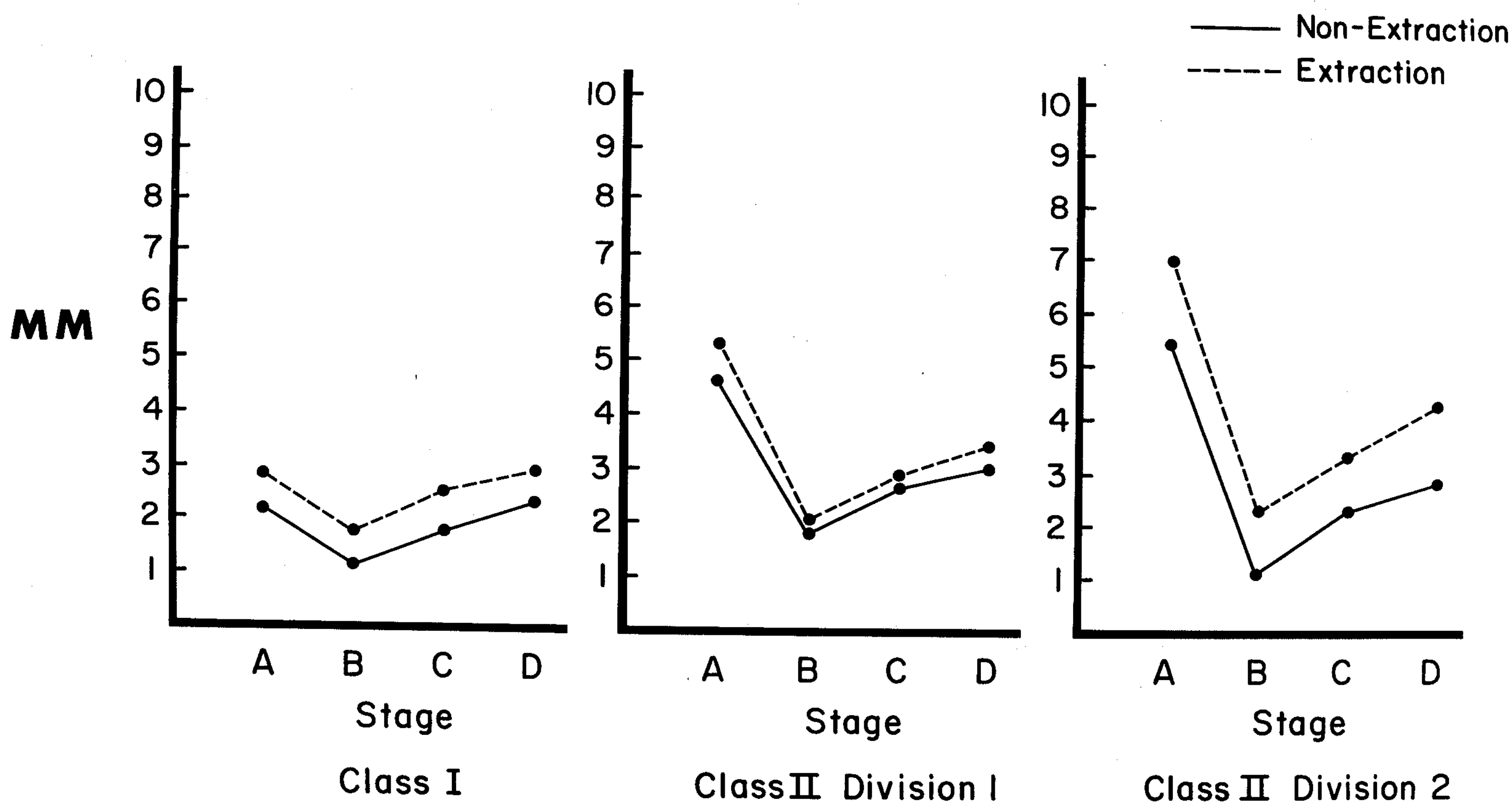
OVERJET

Figure 10



INTERINCISAL ANGLE

Figure 11. Changes in overbite by treatment category (extraction versus non-extraction) Angle classification and stage


Non-Extraction
Extraction
MM
10
9
8
7
6
5
4
3
2
1
A
B
C
D
Stage
Class I
Class II Division 1
Class II Division 2

periods C and D. These effects are illustrated in Figures 8, 9 and 10.

Although the third order interaction (Treatment x Class x Stage) was not significant for the three interincisor variables, the effect of the stages for the two treatment groups (extraction vs. non-extraction) for each of the three classes for the variable overbite is illustrated in Figure 11.

B. Maxillary and mandibular dental variables

Of the twelve dental variables subjected to the mixed anlaysis of variance, seven variables showed significance for the factor Treatment ($p < 0.001$). The means and standard errors for the non-extraction and extraction groups and their levels of significance for each of the variables are listed in Table XXIII (Appendix).

The following six variables from Table XII revealed highly significant differences for the interaction Class x Stage. They were, upper incisor to AP, upper incisor to SN, upper incisor to NA, lower incisor to AP, lower incisor to MP and lower incisor to NB. All were significant at the 0.1 percent level, except lower incisor to AP which was significant at the 1 percent level for the interaction of Class x Stage. Means and standard error for each of these variables for classes, stages and their interaction are found in Tables XIII (a to c) and Table XIV (a to c).

Both maxillary incisor vertical measurements ("upper incisor perpendicular to palatal plane" and "effective distance upper incisor to palatal plane") and the "upper molar perpendicular to palatal plane" were significant for the factor Stage ($p < 0.001$) indicating that consistent

TABLE XII

Levels of Significance for the Mixed Analysis of Variance for 12 Dental Variables

Source of Variation	Treatment (NonExtraction) vs. Extraction)	Class (Class I, Cl.II Div. 1, Cl.II Div. 2)	Treatment x Class	Stage (A,B,C,D)	Treatment x Stage	Class x Stage	Treatment x Class x Stage
Degrees of Freedom	1	2	2	3	3	6	6
1. Upper 1 perp. to PP	–	–	–	***	–	–	–
2. Effect. dist. UI to PP	***	**	–	***	–	–	–
3. Upper 1 to AP	***	***	–	***	–	***	–
4. Upper 1 to SN	***	***	–	–	–	***	–
5. Upper 1 to NA	***	***	–	–	–	***	–
6. Upper 6 perp. PP	–	–	–	***	–	–	–
7. Lower 1 perp. to MP	–	–	–	***	–	–	–
8. Effect. dist. L1 to MP	–	–	–	***	–	–	–
9. Lower 1 to AP	***	***	–	***	–	**	–
10. Lower 1 to MP	***	***	–	***	–	***	–
11. Lower 1 to NB	***	–	–	***	–	***	–
12. Lower 6 perp. MP	–	–	–	***	–	–	–

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
– No significance

TABLE XIII

Effects of Stage and Angle Classification

a) Upper Incisor to AP Line (mm)

Angle Classification		Stages A	B	C	D	Classes
Class I N = 29	Mean	5.39	4.16	3.86	4.02	4.36
	S.E.	±0.26	±0.26	±0.26	±0.26	±0.32
Class II Div. 1 N = 46	Mean	8.05	3.37	3.43	3.81	4.67
	S.E.	±0.21	±0.21	±0.21	±0.21	±0.26
Class II Div. 2 N = 12	Mean	0.94	2.75	1.81	2.00	1.88
	S.E.	±0.41	±0.41	±0.41	±0.41	±0.50
Stages	Mean	4.79	3.42	3.04	3.28	3.63
	S.E.	±0.15	±0.15	±0.15	±0.15	±0.19

b) Upper Incisors to SN (°)

Angle Classification		Stages A	B	C	D	Classes
Class I N = 29	Mean	108.15	105.16	105.32	105.47	106.03
	S.E.	±0.89	±0.89	±0.89	±0.89	±1.04
Class II Div. 1 N = 46	Mean	108.43	98.48	98.02	98.94	100.97
	S.E.	±0.71	±0.71	±0.71	±0.71	±0.83
Class II Div. 2 N = 12	Mean	85.68	98.31	94.69	96.26	93.74
	S.E.	±1.38	±1.38	±1.38	±1.38	±1.62
Stages	Mean	100.76	100.65	99.34	100.26	100.24
	S.E.	±0.51	±0.51	±0.51	±0.51	±0.60

c) Upper Incisor to NA (°)

Angle Classification		Stages A	B	C	D	Classes
Class I N = 29	Mean	26.55	24.95	25.00	24.85	25.33
	S.E.	±0.95	±0.95	±0.95	±0.95	±0.91
Class II Div. 1 N = 46	Mean	27.49	18.89	18.42	19.40	21.00
	S.E.	±0.75	±0.75	±0.75	±0.75	±0.72
Class II Div. 2 N = 12	Mean	3.91	18.81	15.30	16.89	13.74
	S.E.	±1.47	±1.47	±1.47	±1.47	±1.41
Stages	Mean	19.30	20.88	19.53	20.38	20.01
	S.E.	±0.55	±0.55	±0.55	±0.55	±0.55

change occurred for all subjects over the four stages. Of these three maxillary linear dental measurements, only the "effective distance of upper incisor to palatal plane" was significant for the factor Class ($p < 0.01$). None were significant for the interaction Class x Stage or the interaction Treatment x Class x Stage. Means and standard errors for these three variables for Class, Stage and their interaction are presented in Appendix IV (Table XXIV a to c). Examination of the means show that for all subjects there were consistent increases throughout the four stages.

The vertical linear measurements of the lower incisors and lower molar perpendicular to mandibular plane reveal the same trends as previously discussed for the upper incisors and molar, that being, all three were significant only for the factor Stage ($p < 0.001$). Means and standard errors for "lower incisor perpendicular to mandibular plane", "effective distance of lower incisor to mandibular plane" and lower molar perpendicular to mandibular plane for Class, Stage and their interaction are presented in Table XXV (a to c) in Appendix IV.

TABLE XIV

Effects of Stage and Angle Classification

a) Lower Incisor to AP (mm)

Angle Classification		Stages A	B	C	D	Classes
Class I N = 29	Mean S.E.	1.64 ±0.18	1.55 ±0.18	1.07 ±0.18	1.01 ±0.18	1.32 ±0.27
Class II Div. 1 N = 46	Mean S.E.	0.06 ±0.14	0.51 ±0.14	0.38 ±0.14	0.37 ±0.14	0.33 ±0.21
Class II Div. 2 N = 12	Mean S.E.	-2.50 ±0.28	0.06 ±0.28	-0.62 ±0.28	-0.69 ±0.28	-0.94 ±0.41
Stages	Mean S.E.	-0.27 ±0.10	0.71 ±0.10	0.28 ±0.10	0.23 ±0.10	0.24 ±0.15

b) Lower Incisor to MP (^{o})

Angle Classification		Stages A	B	C	D	Classes
Class I N = 29	Mean S.E.	93.68 ±0.63	93.40 ±0.63	92.55 ±0.63	92.60 ±0.63	93.06 ±1.03
Class II Div. 1 N = 46	Mean S.E.	96.24 ±0.50	97.85 ±0.50	97.07 ±0.50	97.54 ±0.50	97.19 ±0.82
Class II Div. 2 N = 12	Mean S.E.	93.79 ±0.99	101.90 ±0.99	99.06 ±0.99	97.67 ±0.99	98.11 ±1.61
Stages	Mean S.E.	94.57 ±0.37	97.72 ±0.37	96.23 ±0.37	95.95 ±0.37	96.12 ±0.60

c) Lower Incisor to NB (^{o})

Angle Classification		Stages A	B	C	D	Classes
Class I N = 29	Mean S.E.	25.66 ±0.65	25.39 ±0.65	23.98 ±0.65	24.03 ±0.65	24.76 ±0.88
Class II Div. 1 N = 46	Mean S.E.	25.51 ±0.51	27.53 ±0.51	26.21 ±0.51	26.23 ±0.51	26.37 ±0.70
Class II Div. 2 N = 12	Mean S.E.	19.73 ±1.00	27.46 ±1.00	24.53 ±1.00	22.14 ±1.00	23.46 ±1.37
Stages	Mean S.E.	23.63 0.14	26.79 0.14	24.90 0.14	24.13 0.14	24.87 ±0.51

C. Angular skeletal measurements

Examination of Table XV reveals that for the factor Treatment, only three variables (SNA, SNB and occlusal plane to FH) showed no significant differences between the extraction and non-extraction groups. Means, standard errors and levels of significance for all the variables for the factor Treatment are found in Table XXIII (Appendix IV).

Of the eleven variables listed in Table XV, only two showed significance for the main effects of Class, of Stage and the interaction of Class x Stage. These two, angle of convexity and ANB, were significant for the main effects Class and Stage and the Class x Stage interaction at the 0.1 percent level.

Other variables (SNA, OM angle and occlusal plane to FH) revealed significant differences for the Class x Stage interaction, for the main effects of Stage but not for the main effects of Class. Means and standard errors for the variables that showed significant differences for the interaction Class x Stage and the main effects of Class and Stage for angle of convexity, ANB, SNA, OM angle and occlusal plane to FH are presented in Table XVI (a to e). Means and standard errors for Class, Stage and the interaction of Class x Stage for the other six variables are found in Tables XXVI (a to c) and XXVII (a to c) (Appendix IV).

D. Linear Skeletal Measurements

Examination of Table XVII listing the six linear skeletal variables subjected to mixed analysis of variance reveals that all six showed statistical significance ($p < 0.001$) for the factor Stage. Only "anterior lower face height" and "length of the mandible" were significant

TABLE XV

Levels of Significance for the Mixed Analysis of Variance for 11 Angular Skeletal Measurements

Source of Variation	Treatment (Non-Extraction or Extraction)	Class (Class I Cl.II Div.1, Cl.II Div.2)	Treatment x Class	Stage (A,B,C,D)	Treatment x Stage	Class x Stage	Treatment x Class x Stage
Degrees of Freedom	1	2	2	3	3	6	6
1. Facial Angle	*	–	–	–	–	–	–
2. Angle of convexity	***	***	–	***	–	***	–
3. ANB	***	***	–	***	–	***	–
4. SNA	–	–	–	***	–	***	–
5. SNB	–	**	–	*	**	–	–
6. Mand. plane to SN	**	**	–	***	–	–	–
7. Mand. plane to FH	**	**	–	***	–	–	–
8. Gonial angle	*	**	–	***	–	–	–
9. Palatal plane to SN	*	**	–	**	–	–	–
10. OM angle	***	–	–	***	–	***	–
11. Occlusal plane to FH	–	–	–	***	–	**	–

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
– No significance

TABLE XVI

Effects of Stage and Angle Classification

a) Angle of Convexity (^{o})

Angle Classification		Stages A	B	C	D	Classes
Class I	Mean	2.75	0.89	0.49	1.08	1.30
N = 29	S.E.	±0.45	±0.45	±0.45	±0.45	±0.85
Class II Div. 1	Mean	9.00	5.73	5.31	4.60	6.16
N = 46	S.E.	±0.35	±0.35	±0.35	±0.35	±0.68
Class II Div. 2	Mean	10.34	4.87	3.71	3.22	5.53
N = 12	S.E.	±0.69	±0.69	±0.69	±0.69	±1.33
Stages	Mean	7.36	3.83	3.17	2.97	4.33
	S.E.	±0.26	±0.26	±0.26	±0.26	±0.49

b) ANB (^{o})

Angle Classification		Stages A	B	C	D	Classes
Class I	Mean	2.48	1.88	1.87	2.10	2.08
N = 29	S.E.	±0.19	±0.19	±0.19	±0.19	±0.30
Class II Div. 1	Mean	5.53	4.17	4.07	3.85	4.40
N = 46	S.E.	±0.15	±0.15	±0.15	±0.15	±0.24
Class II Div. 2	Mean	6.12	4.11	3.64	3.34	4.30
N = 12	S.E.	±0.30	±0.30	±0.30	±0.30	±0.47
Stages	Mean	4.71	3.39	3.20	3.11	3.60
	S.E.	±0.11	±0.11	±0.11	±0.11	±0.18

c) SNA (^{o})

Angle Classification		Stages A	B	C	D	Classes
Class I	Mean	80.52	80.17	80.28	80.56	80.38
N = 29	S.E.	±0.19	±0.19	±0.19	±0.19	±0.67
Class II Div. 1	Mean	80.89	79.52	79.73	79.49	79.91
N = 46	S.E.	±0.15	±0.15	±0.15	±0.15	±0.53
Class II Div. 2	Mean	81.73	79.48	79.28	79.33	79.95
N = 12	S.E.	±0.29	±0.29	±0.29	±0.29	±1.04
Stages	Mean	81.05	79.72	79.76	79.79	80.08
	S.E.	±0.11	±0.11	±0.11	±0.11	±0.38

TABLE XVI (Cont'd)

Effects of Stage and Angle Classification

d) OM Angle (^{o})

Angle Classification		Stages A	B	C	D	Classes
Class I N = 29	Mean S.E.	19.41 ±0.35	19.37 ±0.35	19.58 ±0.35	20.10 ±0.35	19.61 ±0.61
Class II Div. 1 N = 46	Mean S.E.	21.55 ±0.28	17.30 ±0.28	18.16 ±0.28	18.43 ±0.28	18.86 ±0.48
Class II Div. 2 N = 12	Mean S.E.	20.84 ±0.54	16.51 ±0.54	17.12 ±0.54	17.81 ±0.54	18.07 ±0.54
Stages	Mean S.E.	20.60 ±0.20	17.72 ±0.20	18.29 ±0.20	18.78 ±0.20	18.85 ±0.35

e) Occlusal Plane to FH

Angle Classification		Stages A	B	C	D	Classes
Class I N = 29	Mean S.E.	7.89 ±0.52	8.78 ±0.52	7.94 ±0.52	6.85 ±0.52	7.87 ±0.80
Class II Div. 1 N = 46	Mean S.E.	4.36 ±0.41	9.83 ±0.41	8.11 ±0.41	7.02 ±0.41	7.33 ±0.64
Class II Div. 2 N = 12	Mean S.E.	3.65 ±0.80	7.29 ±0.80	5.88 ±0.80	5.77 ±0.80	5.65 ±1.25
Stages	Mean S.E.	5.30 ±0.30	8.64 ±0.30	7.31 ±0.30	6.58 ±0.30	6.95 ±0.46

TABLE XVII

Levels of Significance for the Mixed Analysis of Variance for 6 Linear Skeletal Measurements

Source of Variation	Treatment (Non-Extraction or Extraction)	Class (Class I Cl.II Div.1, Cl.II Div.2)	Treatment x Class	Stage (A,B,C,D)	Treatment x Stage	Class x Stage	Treatment x Class x Stage
Degrees of Freedom	1	2	2	3	3	6	6
1. Ant. Total FH	–	–	–	***	–	–	–
2. Ant. Upper FH	–	–	–	***	–	–	–
3. Ant. Lower FH	–	**	–	***	–	–	–
4. Ramus Length	–	–	–	***	–	–	–
5. Post. Perp. Lower FH	–	–	–	***	–	–	–
6. Mandibular Length	–	***	–	***	–	–	–

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
– No significance

for Class or any other factor and the levels of significance for the main effects of Class were $p < 0.01$ and $p < 0.001$ respectively. Means and standard errors for the main effects of Class and Stage and their interaction is found in Appendix IV (Tables XXVII (a to c) and XXIX (a to c) for the six linear skeletal measurements.

Changes in Overbite

Further examination of overbite was carried out assessing the amount of overbite correction during treatment and subsequent post-treatment changes (Table XVIII). This table shows the mean amounts of correction and the mean amounts of relapse of the corrected value (expressed in millimeters and percent) during the retention and post-retention periods for each Angle class. Finally, the total amount of correction and relapse was compared and the final overbite was related to the original amount of overbite for each Angle class to show the net result after the treatment and post-treatment periods. The type of treatment (extraction vs. non-extraction) was ignored as it was determined that no significant differences were present between the extraction and non-extraction groups for overbite through the four stages for any of the Angle groups (Table X).

To further assess the effects of treatment on overbite, the entire sample was regrouped according to depth of overbite (see Table VII). The results of the mixed analysis of variance for the reorganized sample is found in Table XIX. Means and standard errors for the main effects of depth of bite, stage and their interaction is presented in Table XX. Table XXI shows the changes in overbite of the sample grouped according to depth of bite for the treatment, retention and post-retention periods and the overall changes in overbite for this group. Type of treatment was ignored as it can be seen there were no significant effects of this factor on overbite this group (Table XIX).

Table XVIII Changes in overbite for the sample based on Angle's classification

ANGLE CLASSIFICATION	MEAN OVERBITE AT STAGE (mm.)				CORRECTION OF ORIGINAL OVERBITE		OVERBITE RELAPSE DURING RETENTION		OVERBITE RELAPSE POST RETENTION		TOTAL RELAPSE	RELAPSE / CORRECTION	FINAL OVERBITE / ORIGINAL OVERBITE
	A	B	C	D	A–B mm.	(A–B)/A %	C–B mm.	(C–B)/(A–B) %	D–C mm.	(D–C)/(A–B) %	D–B mm.	(D–B)/(A–B) %	D/A
CLASS I	2.32	1.35	2.06	2.40	0.97	41.8	0.71	73	0.34	35.5	1.05	108	103.4 %
CLASS II DIVISION 1	5.07	1.82	2.67	3.15	3.25	64.1	0.85	26.2	0.48	14.7	1.33	40.9	62.1 %
CLASS II DIVISION 2	6.32	1.84	3.08	3.88	4.48	70.8	1.24	27.7	0.80	17.9	2.04	45.5	61.4 %

TABLE XIX

Mean Squares and Levels of Significance for Mixed Analysis of Variance - Overbite (Treatment - Depth of Bite Group - Stage)

Source of Variation	DF	Mean Squares of Variable Overbite
Treatment	1	0.0673
Depth of Bite	2	1.1725***
Treatment x Depth	2	0.0088
Between Subjects Error	81	0.0226
Stage	3	0.7516***
Treatment x Stage	3	0.0018
Depth of Bite x Stage	6	0.3518***
Treatment x Depth x Stage	6	0.0097
Within Subjects Error	243	0.0090

* p. < 0.05
** p. < 0.01
*** p. < 0.001

TABLE XX

Effects of Stage and "Depth of Overbite" Group

Overbite (mm)

"Depth of Overbite" Group		Stages A	B	C	D	Groups
Shallow (0.0 to 2.5 mm)	Mean	1.08	1.56	1.90	1.80	1.59
	S.E.	±0.22	±0.22	±0.22	±0.22	±0.18
Moderate (2.6 to 5.5)	Mean	4.02	1.51	2.48	3.01	2.75
	S.E.	±0.16	±0.16	±0.16	±0.16	±0.16
Deep (5.5 to 10.0)	Mean	6.50	1.80	2.92	3.54	3.69
	S.E.	±0.17	±0.17	±0.17	±0.17	±0.13
Stages	Mean	3.87	1.62	2.43	2.78	2.68
	S.E.	±0.10	±0.10	±0.10	±0.10	±0.08

Table XXI Changes in overbite for sample based on "depth of overbite" groups

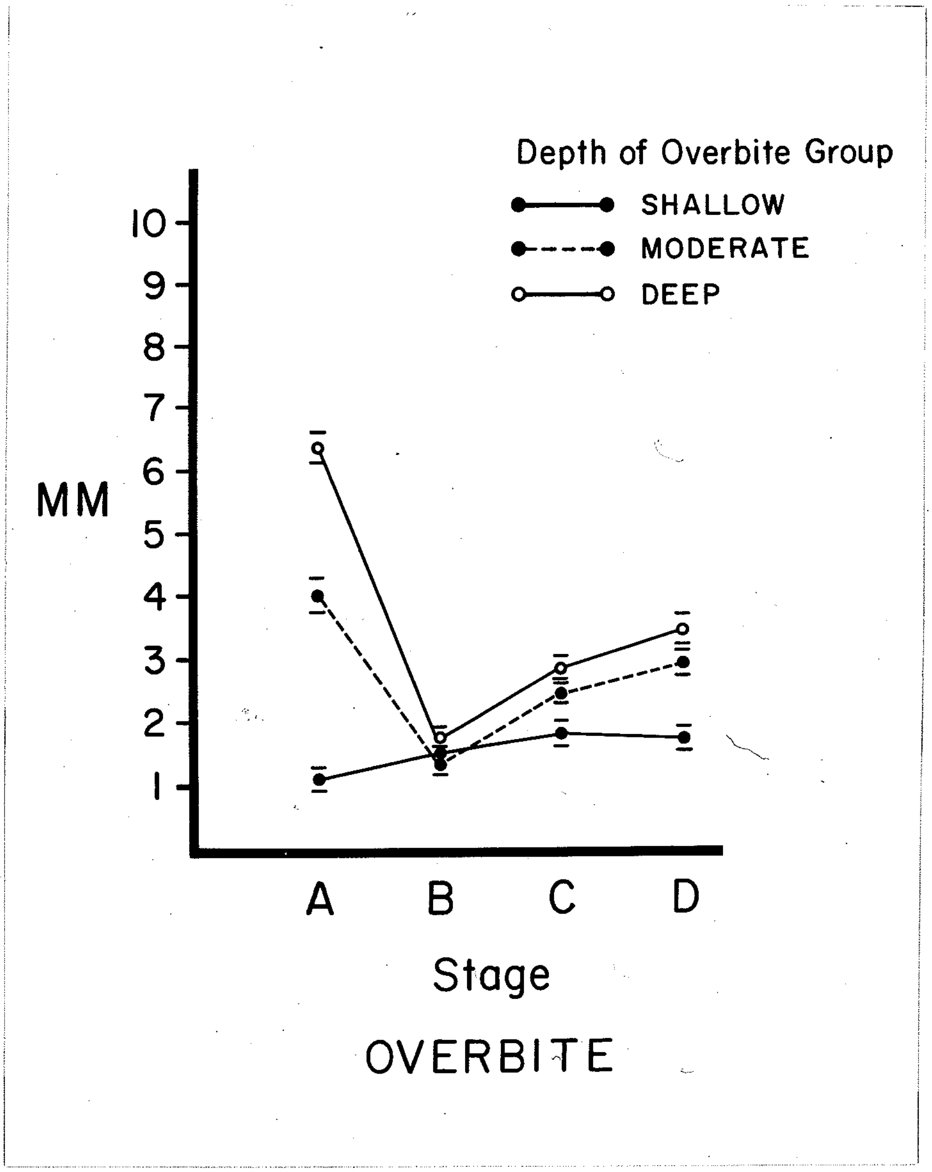
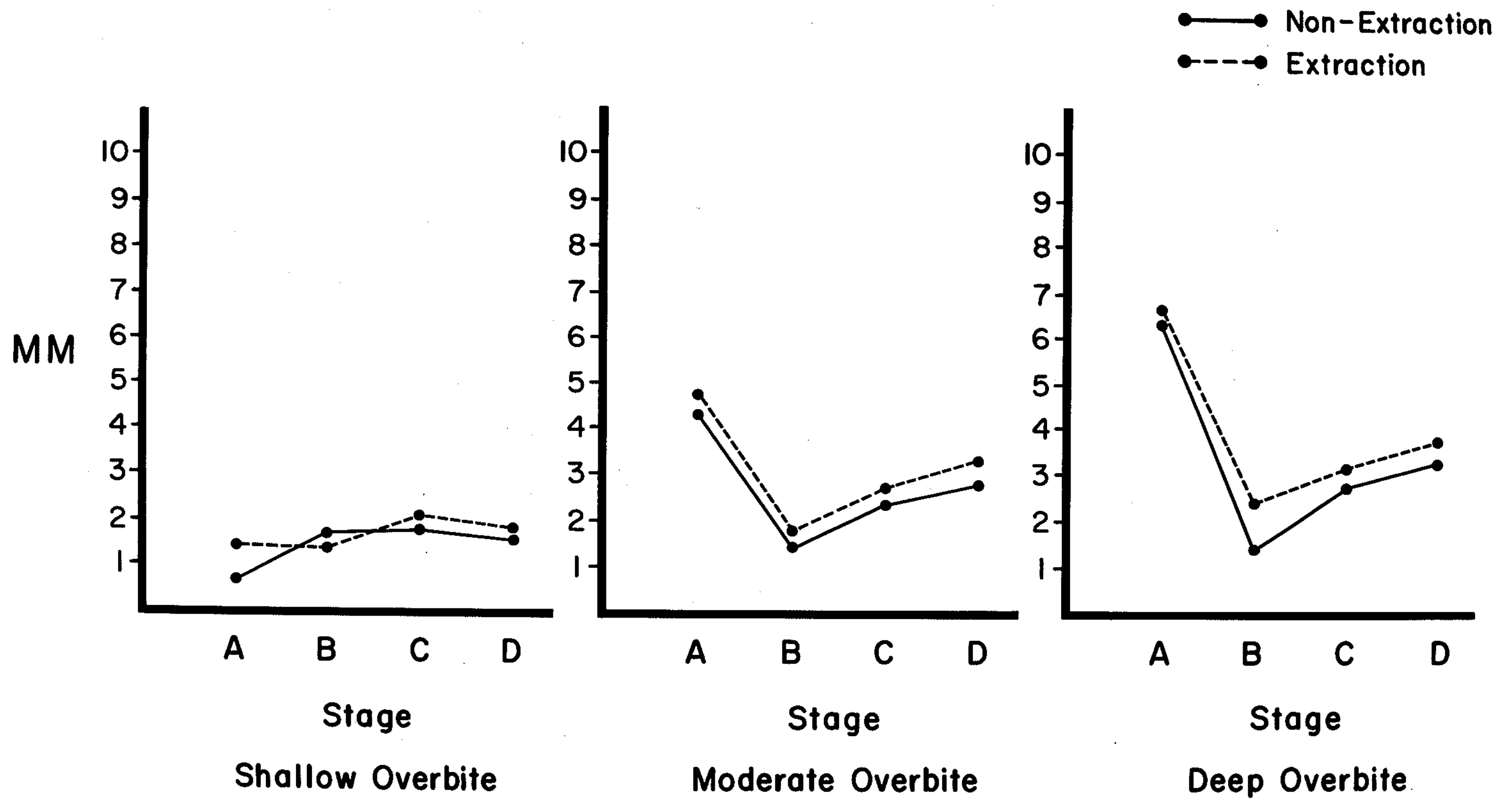


Figure 12. Treatment changes for overbite by stage and "depth of initial overbite" groups.

Figure 13. Changes in overbite by treatment category (extraction versus non-extraction), "depth of initial overbite" group and stage


Non-Extraction
Extraction
MM
10
9
8
7
6
5
4
3
2
1
A
B
C
D
Stage
Shallow Overbite
Moderate Overbite
Deep Overbite

Polygonal Profiles

Figure 14. Computer drawn craniofacial polygon
Angle Class I Stage A

CLASS I STAGE A

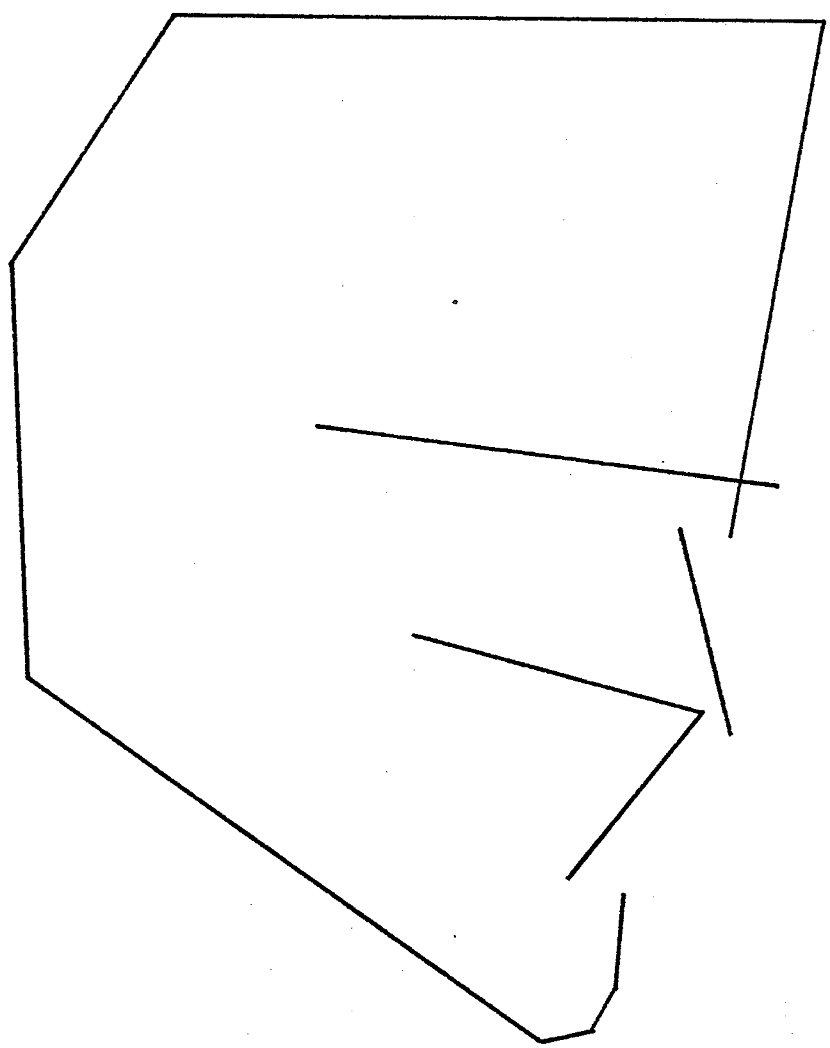


Figure 15. Computer drawn craniofacial polygon
Angle Class II Division 1

CLASS II DIV 1 STAGE A

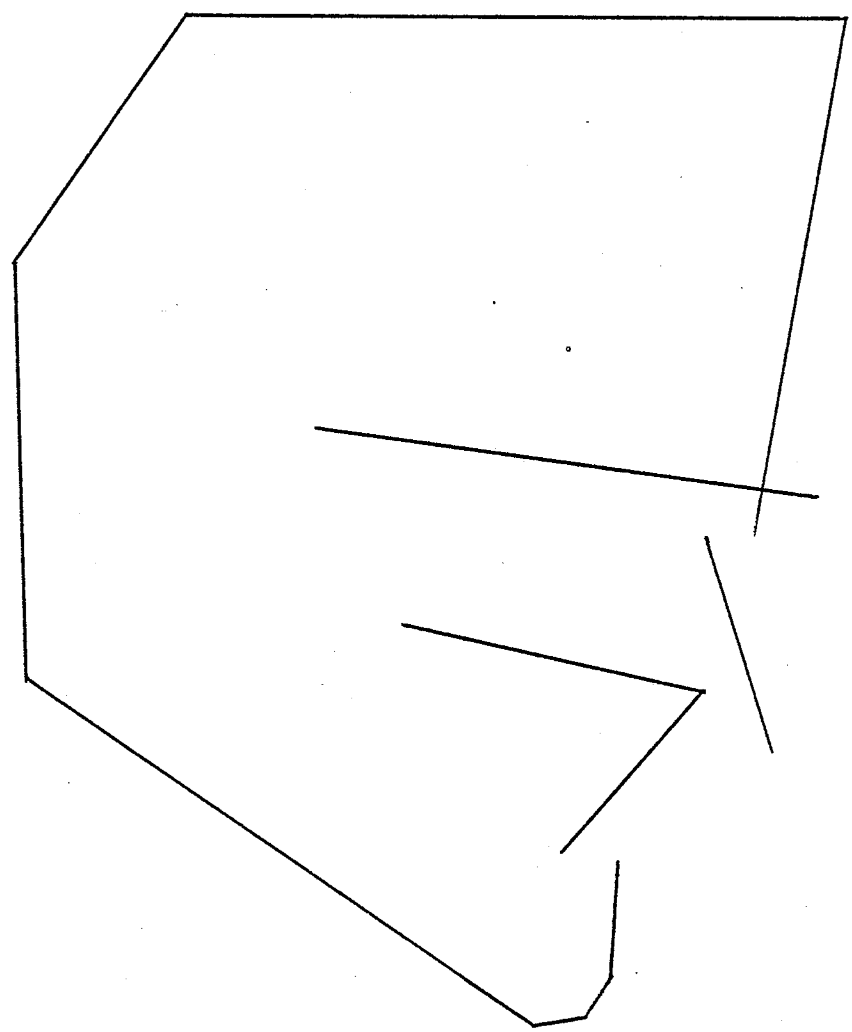
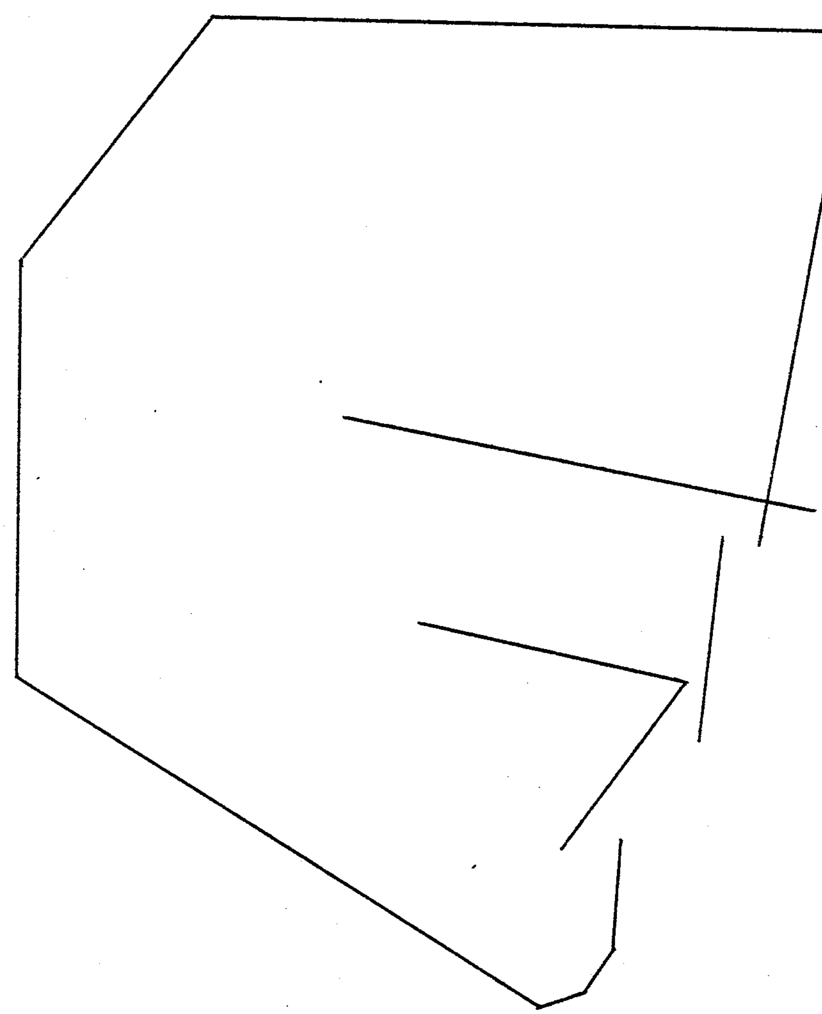
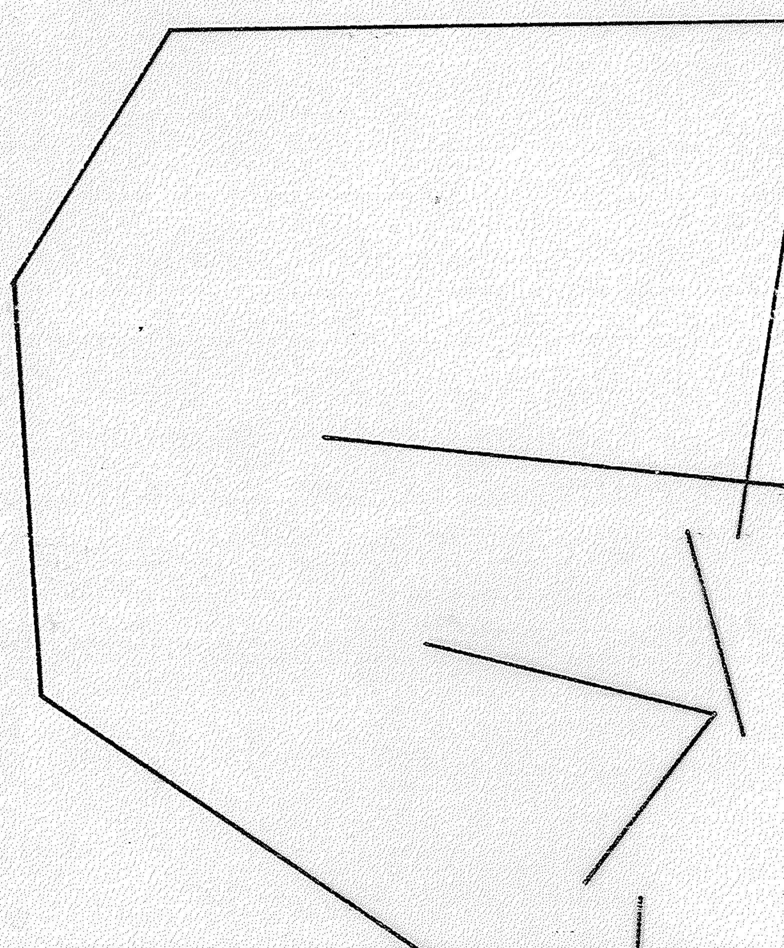


Figure 16. Computer drawn craniofacial polygon
Angle Class II Division 2

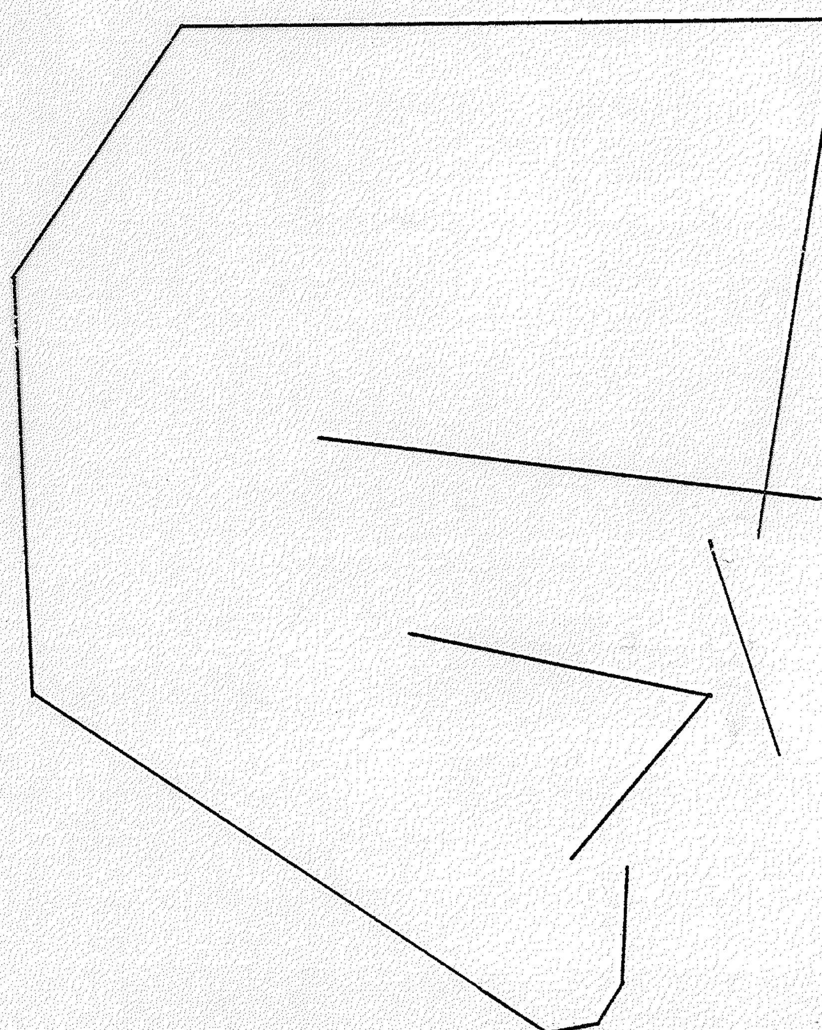
CLASS II DIV 2 STAGE A



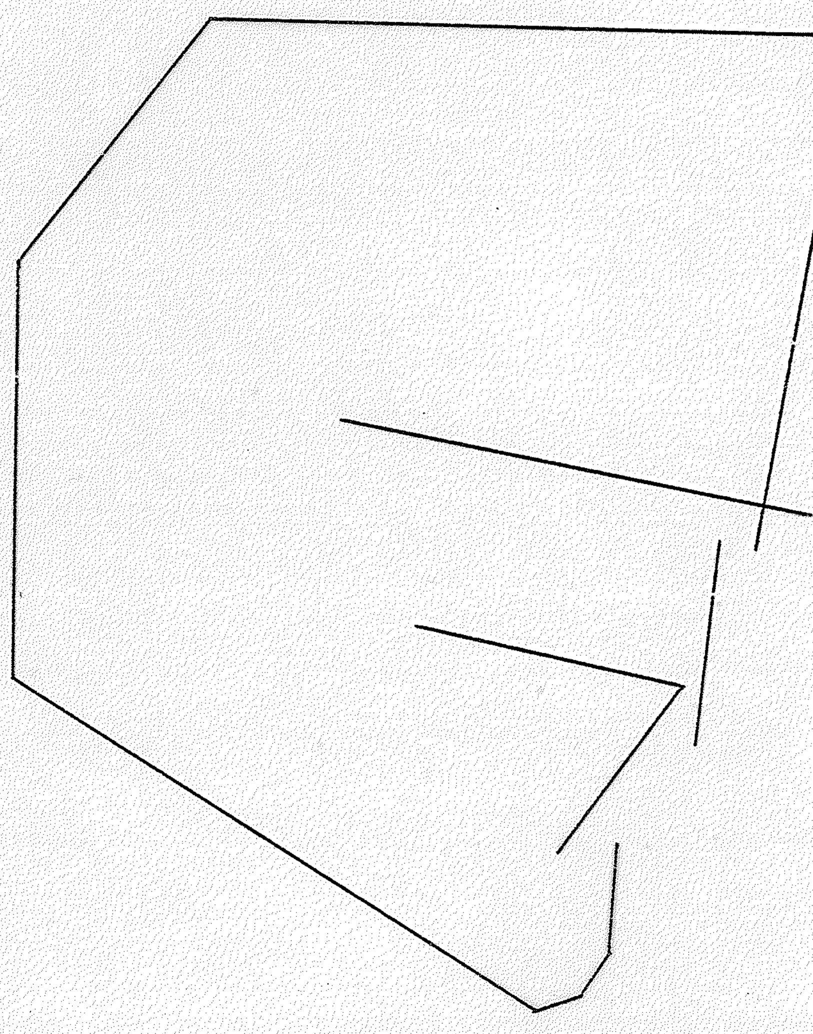
CLASS I STAGE A



CLASS II DIV 1 STAGE A

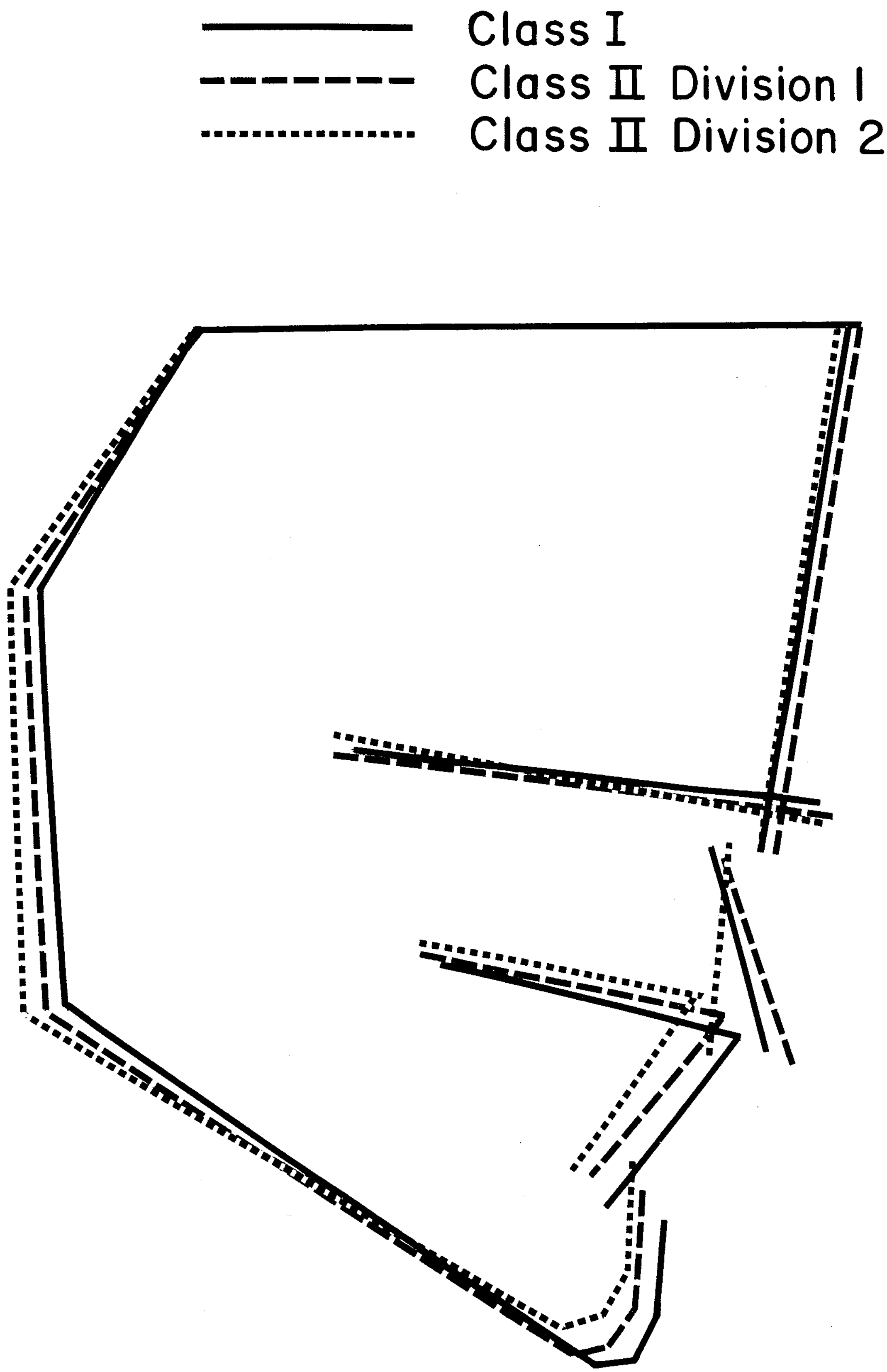


CLASS II DIV 2 STAGE A



Templates for Superimposition

Figure 17. Craniofacial polygons of the three Angle classes (Stage A) superimposed on sella-nasion plane at sella point


Class I
Class II Division 1
Class II Division 2

DISCUSSION

CHAPTER V

DISCUSSION

"Pooled" Correlations of Variables "Associated" with Overbite

On the basis of clinical observations (Grieve, 1928; Strang, 1934), analyses of dental models (Steadman, 1949; Popovich, 1953) and/or lateral cephalometric studies (Fleming, 1961; Schudy, 1966), workers have tried to determine the factors responsible for overbite. In order to examine the factors that may be responsible for overbite in this sample of 87 patients, serial lateral cephalograms representing four periods, pre-treatment (stage A), active treatement (stage B), retention (stage C) and post-retention (stage D), were studied in order to test the association of 46 linear and angular skeletal and dental variables with overbite. The strength of the association of these variables with overbite was tested before and after treatment, retention and post-retention.

To study the association of overbite with other skeletal or dental variables, many authors have utilized correlation coefficients (Prakash and Margolis, 1952; Popovich, 1955; Fleming, 1961; Simons, 1971; Mills, 1973). Results of these and other studies have often been contradictory and trends reported by one author for certain variables may not have been substantiated by others. This could be partly due to the different composition of samples studied as to age, sex, skeletal and/or dental patterns, etc.

The degree of association of the variables studied was tested by "pooling" the correlations of the original sample that was divided into six subgroups based on Angle's classification and sex (Table III). The sample structure and methodology of statistical analysis employed in this study is different than that of other studies on overbite therefore, some caution is advised when making comparisons. Methods of measuring particular variables may also have been different hence, comparison of absolute values is not justified, however, the trends observed in this sample can be compared to other studies.

In order to assess the "aetiologic" effects of the variables studied, only those listed under stage A (pre-treatment) were initially examined. The results of this study show that for this particular sample no one variable was strongly associated with overbite. The ten variables with the highest numerical correlations (Table IX) were of such a magnitude as to be of questionable biological significance. However, it is imperative to note again that these correlations are "averaged" for the six subgroups to give one an overall association for the entire sample, hence, any strong "within group" association may tend to be obscured.

It is of interest to note that the ten most significant variables express both vertical and horizontal relationships at pre-treatment. Those variables expressing vertical associations with overbite are:

(1) Upper molar perpendicular to palatal plane (r = -0.319)

(2) Anterior lower face height (r = -0.315)

(3) Occlusal plane to FH (r = -0.277)

(4) Anterior total face height (r = -0.276)

(5) OM angle (occlusal plane to mandibular plane) (r = 0.240)

(6) Lower molar perpendicular to mandibular plane (r = -0.232)

(7) Mandibular plane to sella-nasion (r = -0.221)

The remaining variables represented horizontal or anteroposterior relationships:

(8) Lower incisor to AP line (mm) (r = -0.439)

(9) Overjet (r = 0.314)

(10) ANB angle (r = 0.289)

Some of these variables have been described by authors as factors related to overbite, although the magnitude of the correlations may vary, the trends between the studies seems to be consistent.

Schudy (1966) noted that the vertical dentoalveolar height of the maxillary molars has a significant effect on the lower face height and inter-maxillary space and thus, greatly affects vertical overbite. Vertical increase of the maxillary molar and its subsequent effects on overbite may not be solely dependent upon the growth of the alveolar process as implied by Schudy. Nemeth and Issacson (1973) found that growth of the maxilla relative to the anterior cranial base (sell-nasion, SN) SN must be considered. Bjork and Skieller (1972) and Lavergne (1977) confirmed in implant studies, that the maxilla as a whole entity, changes in relation to SN and that the growth rotations of the maxilla combined with alveolar growth of the maxillary molars, were reflected in changes of mandibular position. Ultimately, the change in the sagittal and vertical positions of the mandible and the maxilla may show corresponding increases or decreases in overbite of the anterior dental units. For this sample, the trend, as in previous studies (Fleming, 1961; Schudy, 1968), is for overbite to decrease as the vertical height of the maxillary molar increases regardless of other skeletal or dental factors. This was confirmed indirectly by the analysis of variance for the variable "upper molar perpendicular to palatal plane" (Table X) where no significant differences between the three Angle classes (Class I vs. Class II Division 1 vs. Class II Division 2) were detected. This was evident even in the deep overbite Class II Division 2 group that showed the greatest pre-treatment overbite (6.32 ± 0.32 mm). Table XII does reveal that the height of the maxillary molars was significant for the factor Stage ($p < 0.001$) and examinations of the means and standard errors (Table XXV , Appendix) shows that for all patients there was a significant trend for the dentoalveolar height of the maxillary molars to increase during the treatment and post-treatment periods.

From the clinical view, it seems that the dentoalveolar height of the maxillary molars may thus be increased to aid in the decrease of overbite. Questions arise though as to stability of this extrusion and also as to the effects of maxillary molar extrusion on the profile. Burstone (1977) emphasizes that this type of treatment (i.e., molar extrusion) for overbite correction may only be acceptable for certain types of facial patterns and should be avoided in patients exhibiting dolicocephalic or Class II retrognathic skeletal patterns as molar extrusion causes a counterclockwise rotation of the mandible which makes the face appear more retrognathic.

Lower face height has been related indirectly to maxillary and mandibular molar vertical heights. Mills (1973) found that lower face height (LFH) as measured by perpendicular line from palatal plane to menton was significantly smaller in a sample of Angle Class II Division 2 (deep bite) patients when compared to a "normal" control group. The correlation coefficient for LFH with overbite was $r = -0.335$. In this study LFH to overbite (measured from ANS to Me) was $r = -0.315$. This supports the theory that patients exhibiting deep overbite have a diminished LFH and confirms the earlier studies of Wylie (1946), Prakash and Margolis (1952), Popovich (1955) and Dooley (1973). What this vertical relationship ignores is the anteroposterior relationship of the jaws which may further influence LFH proportions relative to the rest of the face. When the original sample was subjected to the analysis of variance, the size of the LFH was significantly different ($p < 0.01$) between the classes (Table XVII) and between the four stages ($p < 0.001$). The Class II Division 2 subgroup exhibited a mean lower face height of 59.87 mm (for all 4 stages) indicating that although the LFH of these deep overbite patients increased throughout the treatment and post-treatment periods, the LFH remained significantly smaller than the LFH of the other Angle classes (Class I, 64.57 mm and Class II Division 1, 63.57 mm). Further examination of the anteroposterior relationship as well as shape and size of the mandible may provide an insight to the size of the lower face in deep bite patients.

As a direct extension of the LFH relationship to overbite, is that of the total face height (TFH) measured in the anterior face (Na-

Me). Wylie (1946) and Richardson (1969) have reported a diminished TFH in "deep bite" patients. Popovich (1955) and Mills (1973) report the same trend existed in their Angle Class II samples. In this study the trend of a smaller total face height was confirmed for all patients regardless of Angle group or sex (r = -0.276). This relationship is no doubt a reflection of the smaller relative size or proportion of the LFH as LFH measurement is an integral part of TFH measurement. The anterior total face height increased throughout the four stages for all the subjects and the differences between the three Angle classes were not significantly different (Table XVII, Table XXVIIIa, Appendix). The upper face height (UFH) showed no relationship to overbite and showed no significant differences between the three classes when the UFH was subjected to the mixed analysis of variance. Like the TFH, the UFH revealed only significant differences for the factor stages at the 0.1% level (Table XVII) and examination of Table XXVIIIb (Appendix) reveals that the upper face (Na-ANS) as in TFH increased in magnitude for all subjects over the four stages. The common factor to LFH and TFH measurements, the mandible, thus seems to play an important role in determination of a deep overbite.

Aside from diminished lower face and total anterior face heights, it has been proposed that longer posterior face heights, smaller gonial angles and smaller mandibular plane and occlusal plane (to SN or FH) values, characterize a deep bite facial pattern (Sassouni, 1969). No significant relationship between overbite and gonial angle or posterior facial height was found. This particular sample showed a slight negative trend ($r = -0.277$) between the variable "occlusal plane to FH" and overbite, indicating that overbite tends to increase in patients with "flat" occlusal planes. Sassouni (1969) notes that when this flat occlusal plane, along with a flat mandibular plane, tend to be parallel the palatal and "optic" planes, the overbite is characteristically deeper.

Another method of relating the occlusal plane to overbite is via the OM angle (occlusal plane to mandibular plane). In low OM angle cases (8^{o} or less) Schudy (1968) notes that deep overbites were featured, while in high OM angle cases (23^{o} or greater), there was a tendency for an "open bite". Schudy (1966) found that there was a negative association between overbite and the OM angle ($r = -0.365$) while, in this study, the pooled correlation was $r = 0.240$. Simons (1971) found no association at all between these two variables in his sample of 70 patients analyzed on the basis of depth of overbite. These contradictory results may be due to sampling size and segregation, methods of measuring the occlusal plane, or the statistical derivation of the correlation coefficients used in these studies. Examination of Table VIII reveals that the same low positive relationship is maintained for stages B, C and D. The diagnostic importance of the OM angle as emphasized by Schudy (1968) should be questioned on the basis of the results of this study and that of Simons (1971). It is hoped that future cephalometric research will attempt to refine the method specifying the occlusal plane and/or its relationship to craniofacial dimensions. With better and more consistent specification of planes, more information may be obtained concerning the relationships of the occlusal plane to those of other craniofacial structures.

The variables "lower molar perpendicular to mandibular plane" and "mandibular plane to SN" both showed low negative correlations with overbite. The former variable represents mandibular molar dentoalveolar height and the correlation of this measurement to overbite, r = -0.232, is similar to that found by Fleming (1961). The correlation of the latter (MP to SN), r = -0.221, confirms the low negative relationship found by Schudy (1968). Schudy implied that as the mandibular plane (to SN or FH) increased, overbite treatment would be easier and stability of overbite be enhanced. Others note that the cant of the mandibular plane may imply growth direction and hence by a factor in assessing overbite stability (Sassouni, 1969; Nemeth and Issacson, 1973; Schudy, 1974). High or low mandibular planes probably affect overbite, in that the cant of this plane dictates a position of the mandible, however, position alone should not dictate to the orthodontist what effect the mandible will have on overbite; dimensions of the mandible should also be assessed. The cant of the mandibular plane may reflect the vertical length of the ramus and/or position of the glenoid fossae. In order then to assess the relationship of the mandible to overbite or any other craniofacial shape, position and dimension must be examined.

The anteroposterior relationship of the lower incisors to overbite has been discussed as an aetiologic factor (Schudy 1968) and as a factor in relapse (Simons, 1971; Kaihlanen, 1975). Schudy (1968) found that the horizontal position of the lower incisor (to AP line) was a very significant factor in the determination of overbite stability. The correlation of the lower incisor to AP (LI to AP) with overbite in Schudy's study was $r = -0.460$, while in this study the pooled correlation was $r = -0.439$ ($p < 0.001$). When the mandibular incisors were positioned back on the mandible, the overbite tended to be greater and because of this, Schudy advocated prolonged lower incisor retention with a fixed cuspid to cuspid retainer. He stressed the horizontal position rather than the vertical position or the axial inclinations of the lower incisors. Recent studies by Simons (1971) and Kaihlanen (1975) question the above hypothesis. Both authors showed that lower incisors that are proclined during treatment tend to upright during the retention and post-retention periods with a subsequent return of overbite. This has been confirmed in this study. Orthodontic treatment and/or growth weakened the relationship (stage B, $r = -0.229$) yet during retention the correlation of LI to AP and overbite returned towards its pre-treatment value (retention, $r = -0.348$; post-retention, $r = -0.395$). Analysis of overbite changes showed that significant relapse occurred for portions of this sample but whether or not any direct cause and effect connection was present has yet to be substantiated.

Both overjet and the ANB angle showed low but positive pooled correlations with overbite ($r = 0.314$ and $r = 0.289$, respectively). The trend for this sample confirms what is often seen clinically, that, as the anteroposterior skeletal discrepancy of the maxilla and the mandible increases, so does overbite (Bjork, 1960). This is especially evident in Class II Division 1 malocclusion cases where a moderate to severe ANB discrepancy is often a reflection of the position of the jaws and the anterior dental units in order to compensate for the overjet may tend to overerupt and create a deeper overbite. The low correlation (pooled) for overjet found in this study (r = 0.314) is similar to that reported by Steadman (1952). He showed, however, that when the correlation coefficient was tested in individual cases, there was no correlation at all between overbite and overjet.

Examination of the pooled correlations of the forty-six variables (Table VIII) shows that in general, for this sample, overbite varies quite independently of most relationships in the face. This suggests a complex multifactorial aetiology that is not just limited to vertical or horizontal relationships in one particular region of the facial complex (i.e., diminished anterior or posterior facial dimensions as suggested by Nahoum 1977). The ten variables previously discussed may only present average trends for this sample. Further studies are indeed warranted to confirm or deny these trends.

What has arisen from this study is the realization that when an individual analyzes malocclusions and their patterns, it is quite evident that categorizing malocclusions into single categories (eg. open bite or deep bite cases or even into the Angle classes) and hoping to defining them adequately or treat them all the same is extremely difficult. It must be determined whether an overbite is due to skeletal or dental factors or a combination of both. Underlying all aspects is one more important, if not the most important factor, that overbite is often only a single component of a malocclusion. Two malocclusions may present with the same amount of overbite and yet have very dissimilar skeletal and/or dental patterns. Studies like those of Wylie (1946), Prakash and Margolis (1952) and Richardson (1969) have segregated their samples based on depth of overbite and reported that various skeletal or dental trends are present. Others like Popovich (1953), Fleming (1961) and Mills (1973) have segregated their samples based on the Angle classification system and then examined overbite.

Examination of the computer drawn polygons (Figures 14, 15, 16) for the three Angle classes (stage A) reveals that although the Angle method of classification is arbitrary, different mean skeletal patterns are evident between the three groups. When the templates of each pre-treatment stage are superimposed on sella-nasion (with origin at sella), the mandible in both Class II Division 1 and Class II Division 2 malocclusion groups was more retrognathic than the mandible in the Class I malocclusion group. As well, in the Class II Division 2 group, the shape of the mandible is such that the gonial angle is more acute and the mandibular plane (MP to SN) is flatter than in the two malocclusion groups. When compared to the Class II Division 1 and Class I malocclusion groups, the palatal plane of the Class II Division 2 group seems tipped down in the anterior. Whether this relative increase in the PP to SN relationship may contribute to the deeper overbite in this group (i.e., by somehow influencing eruption of the upper incisors), is as yet undetermined. Possibly the cant of the palatal plane and maybe the restraining effect of the buccinator mechanism and orbicularis oris may affect the eruption of the incisors into a more vertical position.

Incisal coverage by the lips may also play a role. Mills (1973) found that the vermilion border of the lower lip covered more of the labial surfaces of the maxillary incisors in the deep overbite Class II Division 2 cases than in his control sample ($r = 0.546$, $p < 0.001$). In future changes in the position of the lip line, thickness and/or length and activity of the lips should be examined via cephalometric radiographs and/or electromographic studies.

The Class II Division 1 malocclusion group also exhibits a more retrognathic mandible than the Class I malocclusion group. Both Class II groups exhibit a more distally positioned mandibular articulation with the temporal bone as evidenced by the relationship of the lateral cranial base (N-S-Ar) i.e., position of the glenoid fossa, and this confirms a recent finding by Lavelle (1977). The dorsal articulation may account to some degree for the retrognathic position of the mandible. In the Class II Division 1 group, the ANB discrepancy is the greatest of the three Angle classes. The overbite in this category,(5.07 mm, Table XIa) may be in part, a result of over-eruption of the incisors to compensate for the pronounced overjet.

A comparison of the two Class II groups reveals there are differences between them in the shape and size of the mandible. In the Class II Division 2 group the mandible has a more acute gonial angle and the mandible is shorter than in the Class II Division 1 group.

Because of the above discussed differences, this author feels that grouping Class II Divison 1 and Class II Division 2 patients may have obscured some relevant skeletal and dental patterns that pertain to overbite.

The Angle classification ignores the vertical and transverse relationship; measuring depth of bite ignores the transverse and anteroposterior relation of teeth and jaws. In this study, for example, the Angle Class I cases ranged from very crowded anterior or buccal segments with a deep overbite to bimaxillary (double) protrusions with relatively little overbite and normal alignment of the teeth. When these two extremes are grouped under one broad category, one realizes that certain trends or results will be obscured. Ackerman and Proffit (1969) stated that analogous occlusions and profiles need not be homologous. Similar occlusions and profiles may be caused by different areas of dysplasia and hence, homologous occlusions and profiles often require similar treatment plans, whereas analagous occlusions may require different treatment plans. The problems encountered in this study point out that the classification system used has not included any information describing the aetiology of the occlusion and the facial features. Future studies should be directed at trying to "factor out" what components of the craniofacial complex are related to overbite. Utilization of lateral and/or postero-anterior cephalometric radiographs and dental models may give more information as to factors related to overbite. Malocclusions include other parameters besides overbite. Tooth alignment and dimensions in one or both jaws can be assessed from dental models. The problem of intra-arch variation reflects the relation between tooth size and jaw size perimeter and this may be influenced in part by the oral environment, i.e., by musculature and function. Therefore, intra-arch as well as inter-arch relationships should be accounted for in future studies of overbite. Selection of samples based on more stringent criteria is necessary. Possibly an analysis that incorporates a vertical and transverse as well as an anteroposterior assessment of the skeletal and dental components, tooth alignment, etc., should be used (see Ackerman and Proffit, 1969; Biggerstaff et al. 1977).

Pooling the correlations has proven to be a useful exercise in that it presented associations that were present regardless of skeletal and/or dental patterns. One may find stronger associations by increasing the sample size and segregating the sample based on more stringent criteria. By averaging the correlations between the subgroups some strong trends of overbite association have emerged. Patients exhibiting deeper overbites tend toward diminished maxillary and mandibular molar vertical dentoalveolar heights. The size and position of the mandible seems to play a role in overbite production as patients exhibiting deep overbites tend to show a diminished total and lower face height. The polygons showed that the mandible was slightly smaller and more importantly was more dorsally positioned relative to the maxilla and the anterior cranial base in the deep overbite patients. This is especially evident in the Class II Division 2 malocclusion group. It seems that in this malocclusion sample, the mandible may be the most variable biologic feature. Deep overbite in the Class I skeletal patterns (orthognathic) may be related to dental factors (i.e., crowded anterior teeth, lingually positioned incisors, etc.) while in both of the Class II malocclusions the size and position of the mandible relative to the maxilla may be the primary factor in overbite production.

Changes in Overbite as Determined from the Mixed Analysis of Variance

The results of this study show that, in general, regardless of sample structure (i.e., Angle classes or vertical depth of overbite groups; see Tables XVIII and XXI respectively), overbite that was reduced during treatment showed a tendency to return to its pre-treatment value during the retention and post-retention periods. Effective overbite reduction was evident for all three Angle classes (Table IXa and Figure 8a), but especially so for the deeper overbite Class II Division 1 and Class II Division 2 groups where the initial mean overbites (5.07 mm and 6.32 mm respectively) were reduced to 1.82 mm and 1.84 mm respectively at the end of active treatment. Overbite was significantly different at the 0.1 percent level between each of the classes (Table X) and between each of the four stages. As well, the interaction of Class and Stage was significant ($p < 0.01$) and examination of Table XIa and Figure 8a reveals that this significance was due to the fact that substantially more overbite reduction and relapse occurred in both of the Class II groups. The tendency of overbite decrease during treatment and subsequent post-treatment increase was also present in the Class I malocclusion group. These trends for overbite decrease and subsequent increase are consistent with the studies of Brodie et al. (1938), Magill (1960), Ludwig (1966, 1967), Simons (1971), Hechter (1976) and Levin (1977).

A) Effect of treatment (extraction versus non-extraction) on changes observed in overbite.

When the three Angle classes were examined on the basis of non-extraction vs. extraction therapy, no significant differences in the changes of overbite were noted over the four stages (Figure 11). Overbite decreased during treatment and subsequently relapsed during the post-treatment stages. Although the factor Treatment was significantly different for the non-extraction and extraction groups (Table XXIII, Appendix IV), the fact that Treatment was not significant for the interaction of Treatment x Class, Treatment x Stage or the third order interaction Treatment x Class x Stage (Table X), indicates that the type of treatment (i.e., extraction vs. non-extraction) had no statistically significant effect on the changes of overbite during or after treatment. Furthermore, the non-extraction categories of each Angle class maintained their respective smaller mean overbites consistently throughout the four stages when compared the extraction categories (Figure 9).

Cole (1948), Hernandez (1969), Bishara et al. (1973) and Hechter (1976) reported that the mean overbite relapse in their respective extraction categories relapsed to a greater degree than the non-extraction cases studied. The implication from these studies was that extraction cases showed more relapse. If one realizes, however, that the mean pre-treatment value of overbite may have been greater in their extraction categories than in the non-extraction categories, as was present in this study, the implication that extraction of teeth caused greater relapse may be somewhat tenuous. The results of this study show that although the mean overbite of the extraction categories for each of the Angle groups was greater at all stages, no significant differences between the extraction and non-extraction groups were present. This confirms the studies of Magill (1960), Simons (1971) and Brugg (1973) who all found in their respective studies, that the changes in overbite during the treatment and post-treatment periods were similar in their extraction and non-extraction categories. Magill studied Angle Class I and Class II malocclusions, Brugg studied Angle Class II malocclusions and Simons examined his sample on the basis of the vertical depth of overbite. When the sample used in this study was regrouped according to the initial vertical depth of overbite and type of treatment (Table VII) no significant differences for the non-extraction and extraction categories was determined (Table XIX). Based on the observations that the type of treatment (i.e., non-extraction vs. extraction) was not a significant factor for Class or Stage for any of the variables subjected to the mixed analysis of variance (Tables X, XII, XV and XVII), the extraction and non-extraction categories were combined for future discussion.

A note of caution is advised here. One should not be mislead by the fact that extraction or non-extraction orthodontic therapy showed no statistical difference in the changes in overbite in this sample. Translating this into clinical terms may be hazardous as treatment mechanics and duration of treatment will no doubt vary between these two categories. No doubt the amount of overbite relapse experienced by orthodontists is somewhat dependent upon the initial diagnosis and treatment mechanics employed to correct a particular malocclusion. As Burstone (1977) says, if in correction of overbite incisor intrusion is indicated "differential biomechanics" must be employed in order to achieve intrusion. One should not simply "level the arches" and procline incisor teeth in order to correct the overbite.

One of the problems in examining the research of other authors has been the lack of adequate description of mechanics utilized to facilitate overbite correction. Because of this, generalizations can only be made as to the efficacy of overbite correction. As well, records obtained from institutions such as the University of Manitoba come from patients who have been treated by a number of graduate student operators using a basic edgewise technique with modifications for correction of intraarch problems (rotations, levelling, etc.), retraction of teeth where indicated, and correction of interarch relationships where indicated. In the past, no definite intrusive mechanics as advocated by Burstone (1977) or Ricketts (in Gugino, 1971) have been utilized for specific overbite correction at the University of Manitoba.

B) Changes observed in overbite based on Angle's classification and "depth of initial overbite" groups.

Examination of Table XVIII showing the changes in overbite for the three Angle classes reveals that the Class II Division 2 group had the greatest pre-treatment mean overbite (6.32 mm) and likewise the greatest mean correction (4.48 mm). This correction of 4.48 mm accounted for a 70.8 percent reduction in overbite during treatment. Significantly less amounts of overbite correction were obtained for the Class I and Class II Division 1 malocclusion groups although the latter group showed a mean reduction of 3.25 mm or 64.1 percent of the original value. When considered as a percentage, the amounts of overbite correction for both Class II groups was similar. The post-treatment (stage B) values of overbite for all three groups (Table XVIII) were well within the range of 2.5 mm as advocated by Ricketts (in Gugino, 1971) and would thus indicate an overall satisfactory correction. Individual variation was noted in many patients: as stated earlier, means tend to obscure differences of significance relative to overbite.

The greatest amount of relapse for all groups occurred during the retention period (stage B to C, Table XVIII). The Class I group showed a mean relapse of 0.71 mm or 73 percent of the corrected overbite. Although the absolute mean values of overbite relapse for the Class II Division 1 and Class II Division 2 were 0.85 and 1.24 mm respectively, the percentages were quite similar, 26.2 percent and 27.2 percent, respectively. This amount of relapse during the retention period may be somewhat surprising as it has often been assumed that stability would tend to be maximal with the retention appliances on. The trends of overbite relapse for these three malocclusion groups in the retention period (mean 1.9 years) is similar to that reported by Magill (1960), Ludwig (1966) and Brugg (1973). Magill stated that one half of the overbite settling takes place within two years or less after discontinuation of retention appliances. Huggins and Birch (1964) report that incisor changes (especially maxillary incisors) occur during the first six months after all therapy and retention had been discontinued. It is more than likely that the relapse of overbite in this sample occurred within the initial months of the retention period as Reitan (1969, 1975) has shown that most tissue reorganization after tooth movement occurs within three to four months after appliance removal.

The greatest amount of post-retention overbite relapse occurred in the Class II Division 2 group (0.84 mm or 17.9 percent of overbite correction) as seen in Table XVIII. For the Class I malocclusion group a further relapse of 0.34 mm or 35.5 percent of overbite correction occurred while in the Class II Division 1 group the post-retention relapse was 0.48 mm or 14.7 percent. Comparison of absolute values confirms that the amount of relapse was greatest in the cases with the greatest pre-treatment overbite and also the greatest amount of overbite correction during treatment.

The total amount of relapse of overbite for the Class I malocclusion group was 1.05 mm. Although the amount of total relapse compared to the total amount of overbite correction was greater, the net post-retention overbite (108 percent or 2.40 mm) could hardly be described as unacceptable from a static analysis. Of the 3.25 mm overbite correction for the Class II Division 1 group an overall relapse of 1.33 mm (40.9 percent) of the original correction occurred resulting in a net final overbite of 3.15 mm or 62.1 percent of the original value. Likewise the Class II Division 2 group showed an overall relapse of 2.04 mm (45.5 percent of the overbite correction) for a final overbite of 3.88 mm or 61.4 percent of the original value.

When the entire sample was regrouped on basis of the initial vertical depth of overbite, the deep overbite group exhibited the greatest treatment decrease and post-treatment increases (Table XXI). As discussed above for the Angle classes, extraction or non-extraction therapy had no significant effect on the sample based on depth of overbite (Table XIX). The only significant differences shown were between the depth of overbite groups ($p < 0.001$) and between the stages ($p < 0.001$). As in the table showing overbite changes by class and stage (Table XVIII), the deep overbite group showed changes similar to the Class II Division 2 group for overbite. Examination of the sample whether based on Angle's classification or by depth of overbite shows that deep overbites tend to return to their original pre-treatment values. This study also confirms that of Magill (1960), Ludwig (1966), Simons (1971) and Levin (1977). Simons (1971) found that the patients exhibiting the largest pre-treatment overbite maintained the greatest overbite correction. He suggested that overcorrection of overbite may lead to a more satisfactory result.

In making an evaluation of overbite, we must consider the range of measurements in normal incisal relationships. Steadman (1952) in his study of acceptable occlusion models, found that the mean overbite was 3.1 mm with 65 percent of his sample between 1.2 and 5.0 mm. If one accepts the assumption that overcorrection of overbite is necessary, one would not only expect, but hope for relapse in the direction of what would be "acceptable" for the individual case. Thus, in the cases of a small initial overbite, although the percentage of relapse is greater than in cases with deeper overbites, the actual amount of relapse is less than in those cases with deeper overbites.

One question that arises is that of functional aspects of overbite. Should one overcorrect in order to hopefully end up with an overbite that does not interfere with mandibular movements? Dawson (1974) feels that if deep overbites are corrected, they should be such as to exhibit stable centric relation contacts. He points out, however, that stability is the key.

> "Just having anterior tooth contact may not be sufficient if the contact does not serve as a stop to prevent continuous eruption of the lower anterior teeth. Eruption of the lower anterior teeth into the gingival positions or into the palate, is the number one problem associated with deep overbites. Treatment should always be designed to prevent this from happening or to correct it in a stable fashion if it has already occurred."

C) <u>Factors contributing to overbite relapse.</u>

In order to fully appreciate the reasons for overbite relapse, an examination of those dental and skeletal variables showing significant changes during the same period as overbite was performed. From the mixed analysis of variance, twelve dental and three skeletal variables that were significant for the interaction of Class x Stage, were examined further (Tables X, XII, XV and XVII). Examination of the means and standard errors of each of these fifteen variables revealed that the following variables showed significant treatment and post-treatment changes: "overjet, interincisal angle, upper incisor to AP, upper incisor to SN, upper incisor to NA, lower incisor to AP, lower incisor to MP, lower incisor to NB, OM angle and occlusal plane to FH". Only these dental variables showed any significant post-treatment relapse. The three skeletal variables (angle of convexity, ANB, SNA) that were significant for Class x Stage showed no subsequent post-treatment relapse. The fact that the dental variables showed significant post-treatment return while the skeletal variables did not, does not allow one to rule out the latter as factors that possibly contribute to overbite relapse. On the contrary, Riedel (1975), Bjork and Skeiller (1972) and Schudy (1974) point out that post-treatment growth, particularly of the mandible, may or may not affect dental relapse observed. This must be remembered throughout the ensuing discussion.

During treatment, maxillary incisors were retroclined in both the Class I and Class II Division 1 malocclusion groups, while in the Class II Division 2 group, the already upright maxillary incisors were proclined. Examination of Table XIIIa, b and c reveals that this trend was consistent for the variables upper incisor to AP, upper incisor to SN and upper incisor to NB. For these three variables the deep overbite Class II Division 2 group showed a tendency for the now proclined maxillary incisors to return to their pre-treatment values.

Significant differences at the 0.1 percent were present between the three Angle groups for all stages. Interestingly, the maxillary incisors changed less in retention and post-retention periods in the Class I and Class II Division 1 groups, i.e., once they were retroclined they seemed rather stable. This could be attributed to the influence of the perioral musculature especially in the Class II Division 1 category where clinically one often initially sees the lower lip trapped behind the maxillary incisors. Tipping these teeth back or retracting them bodily to reduce an overjet, seems to be stable in this sample (Table XIIIa, b and c). On the other hand, proclination of incisors in the Class II Division 2 group showed a significant relapse ($p < 0.001$) during the retention period. This deep overbite category exhibited a mean proclination of 12.63° during treatment and a subsequent relapse of 3.62° during retention.

The changes in the axial positions of the maxillary incisors, although statistically significant between the Angle classes and stages, did not correlate significantly with overbite in any of the stages (Table VIII, variable #'s 33, 42, 43). Although there were post-treatment changes in the maxillary incisors it seems that these changes may have significantly affected overbite relapse in the Class II Division 2 group where the incisors were proclined during treatment.

Pre-treatment dentoalveolar vertical height of the maxillary incisors did not contribute to overbite as seen from Table VIII (Pooled correlation variables 30 and 32). This is also confirmed by examination of the means and standard errors (Table XXIVa) and the lack of interaction of Class x Stage in the mixed analysis of variance (Table XII). Although the variable "effective distance upper incisor to PP" was significant for the factor Class ($p < 0.01$), examination of Table XXIVa and b (Appendix) reveals that both measurements of vertical maxillary incisal heights in the pre-treatment deep bite Class II Division 2 group showed slightly diminished vertical heights compared to the other two classes studied. This is interesting in that one may have anticiapted a greater vertical dentoalveolar incisor height in the Class II Division 2 group. The lack of correlation of the dentoalveolar maxillary incisor height with overbite and diminished heights found in the Class II Division 2 group may indicate as in other studies, that the maxillary incisor vertical height is not an aetiologic factor in overbite in all cases (Prakash and Margolis, 1952; Fleming, 1961; Issacson, 1970).

If mechanics were employed to intrude maxillary incisors in the deep bite cases (Class II Division 2), they were on the average unsuccessful as evidenced by the small decrease in the treatment period (Table XXIVa). No effective incisor intrusion was evidence in the Class II Division 1 and Class I groups. In the retention and post-retention periods the mean amounts of vertical incisor increase, although statistically significant for Stage, were still small. One cannot conclude from this study that the vertical incisal changes played any significant role in overbite relapse. This confirms the results of Simons (1971) who, in his sample based on depth of overbite, found that the vertical maxillary incisal changes to be insignificant in the amount of overbite relapse.

In order to be totally certain of tooth changes, metallic implants in the jaws have been advocated to eliminate errors inherent in using skeletal structures for superimposition (Mitchell and Capps, 1971; Issacson et al. 1976). Issacson et al. (1976) note that when using the palatal plane (ANS-PNS) for measuring tooth movement, remodelling of ANS during growth is greater in an inferior direction than PNS, hence, the usual error is to understate the amount of vertical tooth movement than occurred, especially at the incisors. This may affect documentation of the efficacy of overbite mechanics. As implants were unavailable in this study comparison of maxillary and mandibular vertical incisor positions to an untreated control may have given some information as to the relative changes due to growth. This then may have provided a basis to determine if the levelling mechanics at least allowed for "differential eruption" to occur i.e., diminish the vertical growth of the incisors and cause excess eruption of the molars in order to correct the overbite.

Although vertical dentoalveolar height of the maxillary molar showed no significant differences between the three Angle classes at pre-treatment, there was a significant difference for the factor Stage ($p < 0.001$) indicating that for all subjects the vertical height of the maxillary molar increased consistently throughout the four stages (see

Table XXIVc). The greatest increase (1.80 mm) occurred during the treatment period (stage A to B). The magnitude of change during the retention and post-retention periods was considerably smaller. As discussed in the "pooled correlations" the maxillary molar vertical height was significantly correlated to overbite at pre-treatment ($r = -0.319$, $p < 0.01$). Interestingly this relationship was weakened at the post-treatment stage (B) however, the relationship subsequently returned towards its pre-treatment value at post-retention ($r = -0.288$) (see Table IX). This does not imply that the molar heights relapsed, rather as Table XXIVc shows, the molar heights increased overall, while the overbite relapsed. Hence, one could imply that extrusion of maxillary molars is stable and some other factor or factors contributed to overbite relapse.

The two vertical measures of the mandibular incisor and the vertical height of the mandibular molars show similar trends as discussed for the maxillary incisors and molars. No significant differences were present for the factor Class or the interaction of Class x Stage. There were, however, significant differences between the stages ($p < 0.001$) for these three measurements (Table XII). The vertical measures (lower incisor perpendicular to mandibular plane and effective distance lower incisor to mandibular plane) showed no association with overbite (#'s 35 and 38, Table VIII, Pooled Correlations), while the lower molar perpendicular to mandibular plane showed a statistical significant negative relationship to overbite ($r = -0.232$, $p < 0.05$). The lack of correlations for mandibular incisor heights confirms the studies of Prakash and Margolis (1952), Fleming (1961) and Issacson (1970), while Mills (1973) found a low positive correlation for lower incisor height in a sample of Class II Division 2 subjects. The different results no doubt reflect the various samples and statistics used in the other studies. As for the relationship of the lower molar to overbite, the pooled correlations reported in this study confirm the studies of Fleming (1961) and Schudy (1966) that a diminished lower molar height was present in patients with a deeper overbite. This latter relationship was weakened (Table IX) however, the post-retention value r = -0.253 indicates that the pre-treatment relationship returned. As in the case of the maxillary molar, the return of the correlation is due to the relapse of the overbite values not the relapse of mandibular molar vertical positions. Table XXVc (Appendix IV) reveals that regardless of Class or Stage, the vertical dentoalveolar height of the molar relative to the mandibular plane increased throughout the four stages. The dentoalveolar height of the mandibular molar showed a mean increase of 1.79 mm during treatment for all subjects. As for the maxillary incisors, no effective mandibular incisor intrusion was noticed (Table XXVa, b) indicating that in the deep overbite cases, notably the Class II Division 2 group, some other mechanisms of overbite correction were employed. The mechanism for incisor intrusion for the latter group if used, was ineffective. The stability of incisor intrusion has been questioned by Schudy (1968), Simons (1971) and Menzies (1975). These authors note that even if incisor intrusion occurs during treatment, the tendency to relapse is such that the effort may be questioned. On the contrary, Ricketts (in Gugino, 1971), Begg (1977) and Burstone (1977) feel incisor intrusion if properly performed, is stable. The controversy will not be totally resolved until a study utilizing a sample of homologous malocclusions treated with the same sample selection, specifying the type of mechanics and using more reliable reference landmarks eg. implants, is undertaken. Also, to rule out the influence of craniofacial growth, a "non-growing" adult sample should be used.

More noticeable were the horizontal changes of the lower incisors as evidenced by the changes in the mean values of lower incisor to AP, lower incisor to mandibular plane and lower incisor to NB (Table XIVa, b and c). Examination of these tables reveals that in both the Class II groups, the lower incisors were proclined labially while at the end of the post-retention stage, the lower incisors were in almost the same position as pre-treatment. The proclination of the lower incisors was probably due to the effect of banding and levelling the lower arch with reverse curvature in the arch wires as well as the effect of Class II mechanics when used. The Class II Division 2 group exhibited the greatest amount of lower incisor proclination and subsequently the greatest amount of post-treatment return to their original positions. These changes in the horizontal position (axial inclinations) of the lower incisors may have been a direct cause in overbite relapse. As discussed previously, the lower incisor to AP showed the highest statistical "pooled" correlation with overbite ($r = -0.439$, $p < 0.001$). Although the relationship was weakened during treatment, it returned towards its pre-treatment values during the retention and post-retention periods. This was significant at the 0.01 percent level. The results thus show that as the lower incisors were proclined, overbite decreased and that as the lower incisors returned to their original axial inclination, overbite increased. Proclination of incisors via reverse curvature levelling procedures may tend to extrude teeth as well as alter the axial inclination. This may have occurred to both the maxillary and mandibular incisors. Examination of the two variables "effective distance of upper incisor to palatal plane" and "effective distance of lower incisor to mandibular plane" (Table XXIVb, Table XXVb) (Appendix), reveals a consistent linear increase in the incisal heights. These measurements were made from the incisal edges of the respective incisors to the reference plane through the long axis of the teeth. By doing so, one takes into account the changes of the axial position of the tooth and its effect on the incisal edge. If one assumes, therefore, that the proclining of these teeth extruded them, any subsequent axial return may account in part for an increase in overbite. Further examination of this hypothesis is warranted.

The relapse of the lower incisors proclined during treatment probably accounted in part for the post-treatment changes in overjet and the interincisal angle. The Class II Division 1 group exhibited the greatest mean initial overjet (7.71 mm, Table XIa) greatest reduction during treatment (4.85 mm) and subsequently the greatest relapse. On the other hand, the deep overbite Class II Division 2 showed a slight increase in overjet during treatment. This was due, no doubt, to the proclination of upper and lower incisors. For overjet, the results of the "pooled" correlations and the mixed analysis of variance (Table XIa, b) reveal that as overjet increased in the post-treatment periods, so did overbite, for the Class I and Class II Division 1 groups. During the post-treatment periods, the Class II Division 2 group showed a slight decrease in overjet as overbite increased and this interaction of Class and Stage was significant at the 0.01 percent level (Table X, and Figure 8).

The changes in the interincisal angle as seen in the interaction of Class x Stage ($p < 0.001$) were different for each of the three Angle classes. The Class I malocclusion group showed relatively little change while in the Class II Division 1 group the interincisal angle increased 7.82 degrees to 129.19 degrees (see Table XIc, Figure 10). On the other hand, as expected, the steep interincisal angle of the Class II Division 2 group was decreased during treatment due to proclination of maxillary and mandibular incisors. The post-treatment changes of the Class II Division 1 group revealed a slight further increase of the interincisal angle occurred. This was consistent with the relapse of overjet. In this case it was probably due to a combination of slight labial flaring of the upper incisors and lingual uprighting of the proclined lower incisors. In the Class II Division 2 group, considerable relapse of the interincisal angle occurred, yet the correction at Stage D (two years post-retention) showed an overall mean improvement. Here again the increase in the interincisal angle was due to uprighting of the proclined upper and lower incisors. The pooled correlations revealed a very slight association of overbite with the interincisal angle ($r = 0.185$, stage A, Table VIII). This confirms the results of Simons (1971) and Ludwig (1967) but is contrary to the hypothesis of Schudy (1966). It is interesting to note, however, that during the retention and post-retention periods, the relationship of overbite and the interincisal angle increased. The "pooled" correlations for stage C ($r = 0.314$, $p < 0.01$) and stage D ($r = 0.372$, $p < 0.01$) show that as overbite increased, so the interincisal angle increased. This confirms the same trends found by Ludwig (1967) and Dempsey (1974) and Levin (1977). This may suggest that stability of overbite would be enhanced if the proper interincisal relationships obtained during treatment were maintained after treatment.

The question of stability of overbite and the interincisal angle has been debated for some time (Steadman, 1949; Ricketts (in Gugino, 1970); Schudy, 1973; Dempsey, 1974; Riedel, 1975). These authors note that proper interincisal relationships would thus prevent extrusion of the maxillary and mandibular incisors. The implication may be valid if adequate incisal tooth contact, as advocated by Dawson (1974), is obtained. He suggests that the lingual contours of the maxillary incisors are important for lower incisor contact in "centric, long centric, straight protrusive and lateral excursions". Proper "anterior guidance" thus protects the posterior teeth during functional movements of the mandible. If necessary, "correct" contouring of the lingual surfaces of the maxillary incisors is performed and there is an even distribution of anterior centric stops, stability of interincisal relationships are enhanced.

In orthodontics, the method of achieving the proper interincisal relationship should be examined more carefully. Achieving a proper interincisal angle as advocated by Schudy (1968), Andrews (1972) and others does not necessarily imply tooth contact and thus stability. Also, how the incisal relationship is obtained is important for stability. If we assume the relationship is attained solely by proclination of the anterior teeth, as was evident in the Class II Division 2 group, the overbite correction obtained will probably be unstable. On the other hand, if a deep overbite is corrected by incisor intrusion and/or molar extrusion and adequate torquing of the incisors is performed to achieve the desired overbite and interincisal contacts, the stability of the correction will be enhanced. This has been previously emphasized by Graber (1966).

In this study, changes in the occlusal plane relationship (to FH and to MP) were significant for the interaction of the Angle classes by the stages (Table XV). In both of the Class II malocclusion groups, the occlusal plane was "opened" during treatment and subsequently "closed" during the post-treatment periods (Table XVI d and e). These changes confirm the earlier studies of Brodie et al. (1938), Hasstedt (1956), Fogel and Magill (1970) and Riedel (1975). Brugg (1973) found that in his sample of Class II malocclusion patients, the occlusal plane opened during treatment and remained so after retention. No explanation for this was given. It has been proposed that certain types of orthodontic therapy (eg. Class II mechanics) tended to extrude mandibular molars and bicuspids while proclining the incisors. Relapse of the occlusal plane was thought to be due to the reintrusion of the mandibular molars due to the forces generated by the masticatory musculature. The fact that in this sample the mean vertical mandibular molar dentoalveolar height tended to increase throughout treatment, retention and post-retention leads one to question the above hypothesis. More than likely the occlusal plane changes noted here were due to a combination of factors. As the occlusal plane was measured from the tip of the mandibular incisor to the distal buccal cusp of the mandibular molar any changes in the vertical heights of the incisors or molars could account for changes in the cant of the occlusal plane. In this sample, as discussed above, increases in dentoalveolar heights of the mandibular molars and incisors increased throughout the four stages with the lower incisors showing the greatest amounts of increase. That proclination of the lower incisors may have extruded the mandibular incisors somewhat during treatment and the subsequent relapse toward the original axial relationships, may have caused the increase in lower incisor dentoalveolar heights. As discussed previously in the "pooled" correlations, a more uniform method of occlusal plane assessment is warranted in order to yield more information about the changes in the cant of the occlusal plane. Examination of the "functional" occlusal plane (eg. the table of occlusion of the first permanent molar, second bicuspid and first bicuspid) as advocated by Woodside (1976) and Burstone (1977) and the positions of the upper incisors to the upper lip at rest (Burstone, 1977) will give an indication as to the proper cant and level of the occlusal plane and thus one can properly design the mechanics needed to achieve this relationship.

It has been proposed that overbite correction via molar extrusion has a possibility of permanently altering the vertical dimension of the lower face (Nahoum, 1977). Consequently, overbite stability could be enhanced if the lower face height could be developed beyond that expected during growth. Bjork and Skeiller (1972) advocate the use of a retainer with an anterior biteplate to allow extrusion of both maxillary and mandibular molars. This simulates a growth rotation of the mandible at the incisal edges that allows normal posterior facial height increases to lower the mandible vertically and permit the eruption of the molars to keep pace with the rotation. If treatment and retention of this manner is used in younger patients there could be a favourable vertical growth response of the molars and result in a more stable overbite. In adult cases this may not be possible.

The masticatory musculature and its relationship to the facial skeletal pattern may be a dominant force in ultimately determining molar vertical positions as well as jaw positions as shown by McNamara (1977). In an implant study of four non-growing rhesus monkeys following anterior bite plate therapy, he has shown that extruded posterior teeth tended to be intruded after removal of the bite plate. This he concluded was an adaptive response in part due to the effects of the musculature re-establishing the vertical dimension. Further examination of these findings are warranted. By using an animal model such as McNamara did, one could possibly design an experiment to test McNamara's findings in growing rhesus monkeys. Implants would be valuable in assessing skeletal and dental changes but in order to fully understand the "adaptive response" one should also examine changes in the muscle-tendon-bone interface as this area has not received much attention in the past. If, in animal studies, alteration of growth patterns can be effected, one may want to apply some of the principles observed in the treatment of orthodontic patients.

For the skeletal measurements subjected to the mixed analysis of variance no post-treatment relapse occurred (Tables XVII, XXVIIIa, b, c, XXIXa, b, c, Appendix). In fact all skeletal measurements were shown to increase due to growth throughout the four stages. No direct association of the effects of the growth of skeletal complex could be found with overbite changes. This does not imply, however, that growth changes in the maxilla and mandible were not responsible for overbite relapse.

Although it was hoped to determine whether or not "growth rotations" of the maxilla or mandible affected overbite treatment and stability, no definitive patterns of rotations for either jaw were detected. This was no doubt due to the inadequate method of analyzing the growth changes of the skeletal and dental components of the face. The conventional cephalometer and lateral head film have only a limited ability to describe remodelling changes and proportionality changes of the craniofacial skeleton during growth. Changes that are observed on subsequent serial radiographs cannot often be related accurately from one skeletal area to another as there is lack of an adequate reference point. Examining the changes in the dentition alone is hazardous as the dentition cannot be considered in isolation to the skull as a whole. As well, simply examining the increases of dimensions of skeletal components and "correlating" them with overbite now seems inadequate. One must, in the future, examine on an individual basis, the growth direction and magnitude of a particular area of the craniofacial complex. Once directions of growth of an area (eg. condyle, pogonion, etc.) have been determined, one may group patients with similar skeletal and dental patterns, treatment, and growth vectors in order to possibly achieve a better understanding of post-treatment growth changes on overbite.

SUMMARY AND CONCLUSIONS

CHAPTER VI

SUMMARY AND CONCLUSIONS

The purpose of this study was to examine the relationship of incisal overbite to various craniofacial measurements and determine, if possible, what factors may or may not have been responsible for the changes in overbite during and after orthodontic therapy. The lateral cephalometric radiographs of eighty-seven patients treated at the University of Manitoba Graduate Orthodontic Clinic were analyzed using angular and linear measurements from serial radiographs at four stages of treatment (pre-treatment, immediate post-treatment, immediate post-retention and two years post-retention). The patients were grouped into several categories and three different statistical analyses were utilized:

(i) "Pooled" correlations were used in an attempt to correlate incisal overbite to fourty-six cephalometric measurements using six subgroups based on Angle's classification and sex. This method allows one to test for correlations within each subgroup and then yield an "overall average" correlation.

(ii) A mixed factorial analysis of variance was utilized to examine the relationship of angular and linear measurements between the three Angle classes over the four stages and to assess the effect of treatment (extraction vs. non-extraction) on each of these measurements.

(iii) To further assess the changes in overbite, the original sample was grouped into three categories based on the initial vertical depth of overbite. The mixed analysis of variance was applied to the variable overbite to test the effects of treatment (extraction vs. non-extraction) over the four stages between the three groups.

The statistical assessment of the results leads to the following conclusions:

(1) Deep overbites have a complex multifactorial aetiology. The following dental and skeletal factors when examined separately or in combination were associated with overbite:

a) Diminished dentoalveolar vertical heights of the maxillary and mandibular molars.

b) The retrusive relationship of the mandibular incisors (lower incisor to AP).

c) The size, shape and/or position of the mandible (smaller or dorsally positioned mandibles may account in part for the strong negative correlations of lower face height, total face height, occlusal plane and mandibular plane and mandibular incisors position with overbite. As well, the morphology and position of the mandible may also play a role in determining the positive correlation of the ANB angle and overjet with overbite).

(2) The mean vertical dentoalveolar heights of the maxillary and

mandibular incisors were not significantly related to overbite in this malocclusion sample.

(3) The effect of the type of treatment (extraction vs non-extraction) had no significant effect on the treatment and post-treatment changes in overbite.

(4) Regardless of the method of sample segregation (i.e., Angle classes or depth of overbite groups), those patients who exhibited the largest pre-treatment overbite also exhibited the deepest overbite at the end of the two year post-retention period. As well, these patients exhibited the greatest amount of overbite correction and likewise maintained the greatest amount of correction as a result of orthodontic therapy and/or growth.

(5) Regardless of sample structure, the greatest amount of overbite relapse occurred during the so called retention period i.e., in this study within two years after termination of active therapy.

(6) Although some dental variables examined were significantly responsible for overbite decrease during treatment, others were significantly related to overbite relapse during the post-treatment periods.

a) Proclination of the mandibular incisors during treatment was highly associated with overbite decrease. However, the "uprighting" of the mandibular incisors during the retention and post-retention periods accounted for the greatest portion of overbite relapse. This was especially evident in the deep overbite Angle Class II Division 2 malocclusion group.

b) Changes in the axial positions of the mandibular incisors could have also accounted for the changes observed in overjet, interincisal angle and also the occlusal plane.

c) Increases in vertical dentoalveolar height of the molar and bicuspid teeth due to growth and/or treatment were partly responsible for overbite reduction. Vertical dentoalveolar heights of the molars were stable following treatment and in fact continued to increase throughout the retention and post-retention periods.

(7) Other craniofacial and dental relationships not examined in this study may have been responsible in part for overbite relapse.

(8) Stability of the incisal segments should take into account the following factors:

a) The type of mechanics employed to achieve an acceptable overbite (and overjet) relationship. Where indicated, "over-torquing and over-intrusion" may be necessary in view of the relapse tendencies observed in this study.

b) Functional considerations i.e., functional and postural movements of the mandible and their influence on incisal contacts and as well as the effect of the restraining lip musculature on the anterior teeth must be considered. Occlusal adjustment to ensure stable centric relation and other functional position incisal contacts is deemed necessary in the post-treatment periods.

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APPENDICES

APPENDIX I

TABLE XXII

Means, Standard Deviations and Ranges of Ages of Original Sample by Angle Class, Treatment Category and Stage

I. Angle Class I Non-Extraction - (1 female and 7 males) N = 8

Stage A -	13.0 ± 1.2 yr	Range	10.9 to 14.8 yr
B -	15.3 ± 1.0 yr	Range	13.3 to 16.6 yr
C -	16.8 ± 0.8 yr	Range	15.8 to 18.0 yr
D -	18.9 ± 0.8 yr	Range	17.8 to 20.0 yr

II. Angle Class I Extraction - (18 females and 3 males) N = 21

Stage A -	13.1 ± 1.8 yr	Range	9.0 to 16.1 yr
B -	15.2 ± 1.7 yr	Range	12.2 to 18.8 yr
C -	16.9 ± 1.7 yr	Range	13.9 to 20.4 yr
D -	19.3 ± 1.9 yr	Range	16.0 to 24.1 yr

III. Angle Class II Division 1 Non-Extraction - (11 females and 7 males) N = 18

Stage A -	12.1 ± 2.6 yr	Range	8.5 to 20.3 yr
B -	14.6 ± 2.6 yr	Range	12.3 to 23.9 yr
C -	16.1 ± 2.6 yr	Range	12.8 to 24.4 yr
D -	18.6 ± 2.7 yr	Range	14.8 to 25.8 yr

IV. Angle Class II Division 1 Extraction - (18 females and 10 males) N = 28

Stage A -	13.0 ± 1.8 yr	Range	10.5 to 17.9 yr
B -	15.3 ± 1.9 yr	Range	11.8 to 20.3 yr
C -	16.9 ± 2.3 yr	Range	13.9 to 21.8 yr
D -	19.3 ± 1.9 yr	Range	17.2 to 23.9 yr

V. Angle Class II Division 2 Non-Extraction - (5 females and 3 males) N = 8

Stage A -	13.2 ± 1.8 yr	Range	9.6 to 14.9 yr
B -	14.9 ± 2.0 yr	Range	11.1 to 16.9 yr
C -	16.3 ± 1.6 yr	Range	12.9 to 19.3 yr
D -	18.6 ± 1.8 yr	Range	15.1 to 22.0 yr

VI. Angle Class II Division 2 Extraction - (2 females and 2 males) N = 4

Stage A -	13.2 ± 1.9 yr	Range	9.8 to 15.3 yr
B -	15.0 ± 1.7 yr	Range	11.0 to 17.7 yr
C -	16.4 ± 1.8 yr	Range	12.2 to 18.7 yr
D -	18.9 ± 2.0 yr	Range	15.0 to 22.3 yr

TOTAL N = 87

APPENDIX II

GLOSSARY OF LANDMARKS AND PLANES

I. LANDMARKS:

1. Machine Porion

   The most superior point on the ear rods of the cephalostat and believed to represent the mid-point on the upper edge of the external auditory meatus.

2. Sella (S)

   The centre of the sella turcica (pituitary fossa).

3. Frontale

   The most anterior point on the frontal bone determined by a perpendicular line from the SN line.

4. Nasion

   The mid-point of the fronta-nasal suture at its most anterior margin.

5. Nasal Tip

   The most anterior inferior point on the nasal bones.

6. Orbitale

   The deepest point on the infraorbital margin of the bony orbit (bisected).

7. Soft Tissue Nasion

   The most anterior point on the soft tissue nose parallel to nasion.

8. Pronasale

The most anterior point on the contour of the soft tissue nose as measured from the N-Pog line.

9. Soft Tissue "A" Point

The most posterior point of the philtrum of the upper lip.

10. Labrale Superius

The most prominent point on the upper lip measured perpendicular to the N-Pog line.

11. Stomion

The lowest point on the upper lip and the highest point on the lower lip.

12. Labrale Inferius

The most prominent point on the lower lip measured perpendicular to the N-Pog line.

13. Soft Tissue "B" Point

The most posterior point on the contour between the labrale inferius and the soft tissue pogonion.

14. Soft Tissue Pogonion

The most prominent point on the contour of the soft tissue covering of the chin.

15. Menton

The most inferior point on the symphysis menti of the mandible.

16. Gnathion

The most anterior and inferior point on the contour of the chin.

17. Pogonion

The most anterior point on the contour of the chin.

18. "B" Point

The deepest point on the midline contour of the mandible between infradentale and pogonion.

19. The apex of the left mandibular central incisor.

20. The incisal edge of the left maxillary central incisor.

21. The incisal edge of the left mandibular central incisor.

22. The apex of the left maxillary central incisor.

23. "A" Point

The deepest point on the midline contour at the alveolar process between the anterior nasal spine and the alveolar crest of the maxillary central incisor.

24. Anterior Nasal Spine (ANS)

The median, sharp bony process of the maxilla at the lower margin of the anterior nasal opening.

25. Posterior Nasal Spine (PNS)

The process formed by the united projecting ends of the posterior borders of the palatal processes of the palatal bones.

26. Pterygomaxillary Fissure (PTM)

    The projected contour of the fissure formed by the anterior curvature of the pterygoid process and the posterior wall of the tuberosity of the maxilla. The cephalometric radiographic point is the most posterior point on the posterior wall of the maxillary tuberosity.

27. Articulare (Ar)

    The point of intersection of the external dorsal contour of the mandibular condyle and the temporal bone. The midpoint is used when the profile radiograph shows double projections of the rami.

28. Condylion

    The most superior and posterior point on the mandibular condyle.

29. Basion (Ba)

    The most forward and lowest point on the anterior margin of the foramen magnum.

30. Distobuccal cusp tip of the maxillary left first molar.
31. Distobuccal cusp tip of the mandibular left first molar.
32. The most inferior point on the posterior one-third of the lower border of the mandible.
33. Gonion (Go)

    The lowest most posterior, and the most outward point on the angle of the mandibular base line and the line tangent to the posterior border of the ramus.

34-37. Anterior and posterior extensions of the palatal plane used as registration points for maxillary and mandibular superimposition techniques and permitting an assessment of changes in the relationships of the dental units (Chebib, Cleall and Carpenter, 1976).

II. PLANES

1. Sella-Nasion (SN) - A line connecting points sella and nasion.
2. Frankfort Horizontal (FH) - A line extending from the cephalometric porion to orbitale.
3. Palatal Plane (PP) - On the initial radiograph a line connecting anterior and posterior nasal spine and extending to include the transfer points 34 and 35.
4. Occlusal Plane (OP) - A line connecting the distobuccal cusp of the lower first permanent molar to the incisal edge of the mandibular central incisors.
5. Mandibular Plane (MP) - A line tangent to the inferior border of the mandible from menton to gonion.
6. Facial Plane (FP) - line from nasion to pogonion.

APPENDIX III

SKELETAL MEASUREMENTS USED IN THIS STUDY

A. Linear

The 14 skeletal linear measurements are illustrated in Figure 2. All distances were recorded in millimeters.

Distance 1 - Anterior Cranial Base - the linear distance between sella and nasion.

Distance 2 - Posterior Cranial Base - the linear distance between sella and basion.

Distance 3 - Posterior Upper Face Height - the distance between sella and articulare.

Distance 4 - Perpendicular Posterior Total Face Height - the perpendicular distance from the most posterior inferior border of the mandible to the sella nasion line.

Distance 5 - Perpendicular Posterior Lower Face Height - the vertical distance between articulare and the most inferior portion of posterior aspect of the mandible as projected on a perpendicular line from sella-nasion.

Distance 6 - Perpendicular Posterior Upper Face Height - the vertical distance between sella and articulare as projected on a perpendicular line drawn from sella-nasion.

Distance 7 - Ramus Length - the distance from articulare, through a line drawn tangent to the posterior of the ramus, to the intersection of the mandibular plane.

Distance 8 - Mandibular Length - the distance between condylion and pogonion as projected on a line drawn tangent to the lower border of the mandible.

Distance 9 - Perpendicular Anterior Lower Face Height - the perpendicular distance from menton to the palatal plane.

Distance 10 - Anterior Lower Face Height (LFH) - the distance from the anterior nasal spine to menton.

Distance 11 - Perpendicular Anterior Upper Face Height - the perpendicular distance from nasion to the palatal plane.

Distance 12 - Anterior Upper Face Height (UFH) - the distance from nasion to anterior nasal spine.

Distance 13 - Anterior Total Face Height (TFH) - the distance from nasion to menton.

Distance 14 - Chin (P to NB) - the perpendicular distance from pogonion to the NB line.

B. Angular

The 17 angular skeletal measurements are listed in Figure 3 and were recorded in degrees.

Angle 1 - Facial Angle - the relationship of the facial plane (N-Pg) with the Frankfort Horizontal (FH).

Angle 2-Angle of Convexity - the convexity of the skeletal profile as defined the relationship of the nasion-"A" point line and the "A" point-pogonion line.

Angle 3 - SNA - relation of the maxillary apical base to the anterior cranial base (S-N).

Angle 4 - SNB - relation of the mandibular apical base to the anterior cranial base (S-N).

Angle 5 - ANB - apical base relationship.

Angle 6 - SNP - relation of the chin (pogonion) to the anterior cranial base (S-N).

Angle 7 - MP to FH - the relation of the mandibular plane to the Frankfort Horizontal.

Angle 8 - MP to SN - the relation of the mandibular plane to the anterior cranial base (S-N).

Angle 9 - PP to SN - relation of the palatal plane to the anterior cranial base.

Angle 10 - FH to SN - relation of the Frankfort Horizontal to the anterior cranial base.

Angle 11 - Occlusal Plane to SN - relation of the occlusal plane (i.e., line from the tip of lower incisor to distobuccal cusp of lower molar) to the anterior cranial base.

Angle 12 - Occlusal Plane to FH - relation of the occlusal plane to Frankfort Horizontal.

Angle 13 - OM Angle - the relation of the occlusal plane to mandibular plane.

Angle 14 - Midline Cranial Base (N-S-Ba) - the relation of the posterior cranial base (basion-sella) to the anterior cranial base (sella-nasion).

Angle 15 - Lateral Cranial Base (N-S-Ar) - the relation of the lateral aspect of the cranial base (articulare-sella) to the anterior cranial base.

Angle 16 - Posterior Facial Angle (S-Ar-Go) - the relation of the posterior upper and lower face heights.

Angle 17 - Gonial Angle - the relation of the ramus to the mandibular plane.

APPENDIX III (continued)

DENTAL MEASUREMENTS

A. Linear

The 13 linear dental measurements used in this study are illustrated in Figures 4 and 5.

Distance 1 - Overjet - the horizontal distance between the left maxillary central incisal edge and the left mandibular central incisal edge as projected on the palatal plane.

Distance 2 - Overbite - the distance between the left mandibular central incisal edge and the left maxillary central incisal edge as measured on a line perpendicular to the palatal plane.

Distance 3 - Upper Incisor to Palatal Plane (UI PP) - the perpendicular distance of the maxillary incisal edge to the palatal plane.

Distance 4 - Effective Distance of the Upper Incisor to Palatal Plane - the distance from the maxillary central incisal edge to the palatal plane through the long axis of this tooth.

Distance 5 - Upper Incisor to AP Line (UI AP) - the perpendicular distance of the maxillary central incisor to the AP line.

Distance 6 - Upper Molar to Palatal Plane (U6 PP) - the perpendicular distance of the distobuccal cusp of the maxillary first permanent molar to the palatal plane.

Distance 7 - Maxillary Arch Length - the sagittal arch length as defined by line from the maxillary central incisor to the distobuccal cusp of the maxillary first permanent molars.

Distance 8 - Lower Incisor to Mandibular Plane (LI MP) - the perpendicular distance of the incisal edge of the mandibular central incisor to the mandibular plane.

Distance 9 - Effective Distance of the Lower Incisor to Mandibular Plane - the distance from the mandibular incisal edge to the mandibular plane through the long axis of this tooth.

Distance 10 - Lower Incisor to AP Line (LI AP) - the perpendicular distance between the mandibular central incisor to the AP line.

Distance 11 - Lower Incisor to NB Line (LI NB) - the perpendicular distance between the mandibular central incisor to the NB line.

Distance 12 - Lower Molar Perpendicular to the Mandibular Plane (L6 MP) - the perpendicular distance from the distobuccal cusp of the mandibular first molar to the mandibular plane.

Distance 13 - Mandibular Arch Length - the sagittal arch length as defined by the distance between the mandibular central incisal edge to the distobuccal cusp of the mandibular first permanent molar.

B. <u>Angular</u>

The 7 angular dental measurements are illustrated in Figure 6.

Angle 1 - Interincisal Angle - the relationship between the long axis of the maxillary central incisor and mandibular central incisor.

Angle 2 - Upper Incisor to SN (UI SN) - the relationship of the long axis of the maxillary central incisor to the cranial base as defined by Sella-Nasion.

Angle 3 - Upper Incisor to PP (UI PP) - the relationship of the long axis of the maxillary central incisor to the palatal plane.

Angle 4 - Upper Incisor to NA line (UI NA) - the relationship of the long axis of the maxillary central incisor to the anterior profile line-NA (Steiner, 1960).

Angle 5 - Lower Incisor to MP (LI MP) - the relationship of the long axis of the mandibular central incisor to the mandibular plane.

Angle 6 - Lower Incisor to OP (LI OP) - the relationship of the long axis of the mandibular central incisor to the occlusal plane.

Angle 7 - Lower Incisor to NB Line (LI NB) - the relationship of the profile line-NB (Steiner, 1960).

TABLE XXIII

Main Effects of Treatment (Extraction vs. Non-Extraction)

Treatment		Overbite (mm)	Overjet (mm)	Inter-Incisal Angle (°)	UI perp. PP (mm)	Effective Distance UI to PP (mm)	UI AP (mm)	UI SN (°)	UI NA (°)	U6 Perp. to PP (mm)
Non-Extraction N = 136	Mean	1.57	3.34	127.21	26.54	28.78	4.25	103.21	22.81	19.75
	S.E.	±0.16	±0.16	±1.25	±0.48	±0.47	±0.30	±0.96	±0.84	±0.36
Extraction N = 212	Mean	3.43	3.52	135.43	26.04	27.40	3.02	97.29	17.32	19.78
	S.E.	±0.13	±0.13	±1.00	±0.39	±0.38	±0.24	±0.77	±0.67	±0.29
Significance		***	NS	***	NS	***	***	***	***	NS

Treatment		LI Perp. MP (mm)	Effective Distance LI MP (mm)	LI AP (mm)	LI MP (°)	LI NB (°)	L6 Perp. MP (mm)	OM Angle (°)	Occlusal Plane to FH (°)
Non-Extraction N = 136	Mean	37.54	38.28	0.93	98.37	26.73	28.28	17.53	6.90
	S.E.	±0.50	±0.52	±0.25	±0.95	±0.81	±0.42	±0.56	±0.74
Extraction N = 212	Mean	36.80	37.13	-0.46	93.86	23.00	27.42	20.16	6.99
	S.E.	±0.40	±0.41	±0.20	±0.76	±0.65	±0.34	±0.45	±0.59
Significance		NS	NS	***	***	***	NS	***	NS

TABLE XXIII (Continued)

Treatment		Facial Angle (°)	Angle of Convexity (°)	ANB (°)	SNA (°)	SNB (°)	MP to SN (°)	MP to FH (°)	Gonial Angle (°)	PP to SN (°)
Non-Extraction	Mean	85.51	1.96	3.05	80.17	77.08	31.19	24.48	123.31	7.51
N = 136	S.E.	±0.62	±0.79	±0.28	±0.62	±0.58	±0.83	±0.87	±0.92	±0.57
Extraction	Mean	83.64	5.71	4.15	80.00	75.82	33.24	27.04	125.80	8.93
N = 212	S.E.	±0.50	±0.63	±0.26	±0.49	±0.47	±0.66	±0.69	±0.74	±0.46
Significance		*	***	***	NS	NS	**	**	**	*

Treatment		Anterior TFH (mm)	Anterior UFH (mm)	Anterior LFH (mm)	Ramus Length (mm)	Posterior LFH (mm)	Mandibular Length (mm)
Non-Extraction	Mean	112.08	50.00	63.30	45.93	51.53	101.42
N = 136	S.E.	±1.14	±0.48	±0.96	±0.65	±0.68	±0.99
Extraction	Mean	110.46	50.22	62.04	44.90	50.50	99.54
N = 212	S.E.	±0.96	±0.39	±0.77	±0.52	±0.54	±0.80
Significance		NS	NS	NS	NS	NS	NS

Levels of significance

*   p. < 0.05

**   p. < 0.01

***   p. < 0.001

NS   No Significance

TABLE XXIV

Effects of Stage and Angle Classification

a) Upper Incisor Perpendicular to Palatal Plane (mm)

Angle Classification		Stage A	B	C	D	Classes
Class I	Mean	26.09	26.57	26.93	27.12	26.68
N = 29	S.E.	±0.21	±0.21	±0.21	±0.21	±0.52
Class II Div. 1	Mean	25.76	26.79	27.11	27.50	26.79
N = 46	S.E.	±0.16	±0.16	±0.16	±0.16	±0.42
Class II Div. 2	Mean	25.37	24.69	25.69	25.87	25.41
N = 12	S.E.	±0.32	±0.32	±0.32	±0.32	±0.82
Stages	Mean	25.74	26.02	26.57	26.83	26.29
	S.E.	±0.12	±0.12	±0.12	±0.12	±0.30

b) Effective Distance Upper Incisor to Palatal Plane (mm)

Angle Classification		Stage A	B	C	D	Classes
Class I	Mean	29.00	28.77	29.25	29.44	29.11
N = 29	S.E.	±0.20	±0.20	±0.20	±0.20	±0.51
Class II Div. 1	Mean	29.03	28.11	28.59	28.98	28.68
N = 46	S.E.	±0.16	±0.16	±0.16	±0.16	±0.41
Class II Div. 2	Mean	25.75	26.44	26.50	27.19	26.47
N = 12	S.E.	±0.31	±0.31	±0.31	±0.31	±0.80
Stage	Mean	27.93	27.77	28.11	28.53	28.09
	S.E.	±0.11	±0.11	±0.11	±0.11	±0.30

c) Upper Molar Perpendicular to Palatal Plane (mm)

Angle Classification		Stage A	B	C	D	Classes
Class I	Mean	18.45	20.60	20.96	20.86	20.22
N = 29	S.E.	±0.23	±0.23	±0.23	±0.23	±0.39
Class II Div. 1	Mean	17.18	19.11	20.06	20.48	19.21
N = 46	S.E.	±0.18	±0.18	±0.18	±0.18	±0.31
Class II Div. 2	Mean	18.50	19.81	20.69	20.50	19.88
N = 12	S.E.	±0.35	±0.35	±0.35	±0.35	±0.61
Stage	Mean	18.04	19.84	20.57	20.61	19.77
	S.E.	±0.13	±0.13	±0.13	±0.13	±0.23

TABLE XXV

Effects of Stage and Angle Classification

a) Lower Incisor Perpendicular to Mandibular Plane (mm)

Angle Classification		Stage A	B	C	D	Classes
Class I N = 29	Mean S.E.	36.50 ±0.21	37.71 ±0.21	38.16 ±0.21	38.35 ±0.21	37.68 ±0.55
Class II Div. 1 N = 46	Mean S.E.	37.24 ±0.17	36.85 ±0.17	37.59 ±0.17	38.20 ±0.17	37.47 ±0.43
Class II Div. 2 N = 12	Mean S.E.	36.12 ±0.33	35.87 ±0.33	36.44 ±0.33	37.00 ±0.33	36.36
Stages	Mean S.E.	36.62 ±0.12	36.81 ±0.12	37.40 ±0.12	37.85 ±0.12	37.17 ±0.31

b) Effective Distance Lower Incisor to Mandibular Plane (mm)

Angle Classification		Stage A	B	C	D	Classes
Class I N = 29	Mean S.E.	37.09 ±0.21	38.15 ±0.21	38.55 ±0.21	38.75 ±0.21	38.14 ±0.21
Class II Div. 1 N = 46	Mean S.E.	37.69 ±0.17	37.37 ±0.17	38.21 ±0.17	38.83 ±0.17	38.02 ±0.44
Class II Div. 2 N = 12	Mean S.E.	36.44 ±0.33	37.00 ±0.33	36.94 ±0.33	37.44 ±0.33	36.95 ±0.87
Stages	Mean S.E.	37.07 ±0.12	37.51 ±0.12	37.90 ±0.12	38.34 ±0.12	37.70 ±0.32

c) Lower Molar Perpendicular to Mandibular Plane (mm)

Angle Classification		Stage A	B	C	D	Classes
Class I N = 29	Mean S.E.	26.47 ±0.23	28.32 ±0.23	28.93 ±0.23	28.73 ±0.23	28.09 ±0.45
Class II Div. 1 N = 46	Mean S.E.	25.93 ±0.19	27.88 ±0.19	28.54 ±0.19	29.05 ±0.19	27.85 ±0.36
Class II Div. 2 N = 12	Mean S.E.	26.37 ±0.36	27.75 ±0.36	28.06 ±0.36	28.25 ±0.36	27.61 ±0.70
Stages	Mean S.E.	26.26 ±0.14	27.95 ±0.14	28.51 ±0.14	28.68 ±0.14	27.85 ±0.26

TABLE XXVI

Effects of Stage and Angle Classification

a) Facial Angle (^{o})

Angle Classification		Stage A	B	C	D	Classes
Class I	Mean	85.72	85.18	85.45	85.98	85.58
N = 29	S.E.	±0.41	±0.41	±0.41	±0.41	±0.67
Class II Div. 1	Mean	84.66	83.98	84.39	84.84	84.47
N = 46	S.E.	±0.32	±0.32	±0.32	±0.32	±0.53
Class II Div. 2	Mean	82.93	83.55	84.34	83.89	83.68
N = 12	S.E.	±0.63	±0.63	±0.63	±0.63	±1.04
Stages	Mean	84.44	84.23	84.73	84.90	84.58
	S.E.	±0.23	±0.23	±0.23	±0.23	±0.39

b) SNB (^{o})

Angle Classification		Stage A	B	C	D	Classes
Class I	Mean	77.99	78.27	78.38	78.41	78.26
N = 29	S.E.	±0.16	±0.16	±0.16	±0.16	±0.63
Class II Div. 1	Mean	75.31	75.30	75.61	75.60	75.46
N = 46	S.E.	±0.13	±0.13	±0.13	±0.13	±0.50
Class II Div. 2	Mean	75.57	75.33	75.61	75.94	75.61
N = 12	S.E.	±0.25	±0.25	±0.25	±0.25	±0.98
Stages	Mean	76.29	76.30	76.54	76.65	76.45
	S.E.	±0.93	±0.93	±0.93	±0.93	±0.93

c) Gonial Angle (^{o})

Angle Classification		Stage A	B	C	D	Classes
Class I	Mean	127.25	126.16	126.04	125.52	126.24
N = 29	S.E.	±0.42	±0.42	±0.42	±0.42	±1.00
Class II Div. 1	Mean	126.92	126.85	125.95	125.33	126.26
N = 46	S.E.	±0.33	±0.33	±0.33	±0.33	±0.79
Class II Div. 2	Mean	121.59	121.83	120.74	120.48	121.16
N = 12	S.E.	±0.65	±0.65	±0.65	±0.65	±1.55
Stages	Mean	125.25	124.95	124.24	123.78	124.55
	S.E.	±0.24	±0.24	±0.24	±0.24	±0.58

TABLE XXVII

Effects of Stage and Angle Classification

a) Mandibular Plane to SN (°)

Angle Classification		Stage A	B	C	D	Classes
Class I	Mean	33.89	33.62	32.95	32.91	33.35
N = 29	S.E.	±0.25	±0.25	±0.25	±0.25	±0.90
Class II Div. 1	Mean	33.87	34.29	33.44	32.95	33.64
N = 46	S.E.	±0.20	±0.20	±0.20	±0.20	±0.71
Class II Div. 2	Mean	30.30	30.13	29.76	28.47	29.66
N = 12	S.E.	±0.39	±0.39	±0.39	±0.39	±1.39
Stages	Mean	32.69	32.68	32.05	31.44	32.21
	S.E.	±0.15	±0.15	±0.15	±0.15	±0.52

b) Mandibular Plane to FH (°)

Angle Classification		Stage A	B	C	D	Classes
Class I	Mean	27.38	28.21	27.57	26.99	27.53
N = 29	S.E.	±0.43	±0.43	±0.43	±0.43	±0.94
Class II Div. 1	Mean	25.95	27.19	26.32	25.50	26.24
N = 46	S.E.	±0.35	±0.35	±0.35	±0.35	±0.74
Class II Div. 2	Mean	24.52	23.84	23.06	22.61	23.51
N = 12	S.E.	±0.68	±0.68	±0.68	±0.68	±1.46
Stages	Mean	25.95	26.41	25.65	25.03	25.76
	S.E.	±0.25	±0.25	±0.25	±0.25	±0.54

c) Palatal Plane to SN (°)

Angle Classification		Stage A	B	C	D	Classes
Class I	Mean	6.60	6.61	6.60	6.49	6.56
N = 29	S.E.	±0.23	±0.23	±0.23	±0.23	±0.66
Class II Div. 1	Mean	7.24	8.23	8.50	8.53	8.13
N = 46	S.E.	±0.18	±0.18	±0.18	±0.18	±0.50
Class II Div. 2	Mean	9.69	10.33	10.08	9.78	9.97
N = 12	S.E.	±0.35	±0.35	±0.35	±0.35	±0.97
Stages	Mean	7.84	8.39	8.39	8.25	8.22
	S.E.	±0.13	±0.13	±0.13	±0.13	±0.36

TABLE XXVIII

Effects of Stage and Angle Classification

a) Anterior Total Face Height (mm)

Angle Classification		Stage A	B	C	D	Classes
Class I	Mean	108.91	113.88	114.71	114.27	112.94
N = 29	S.E.	±0.54	±0.54	±0.54	±0.54	±1.23
Class II Div. 1	Mean	106.45	112.71	113.94	115.00	112.03
N = 46	S.E.	±0.43	±0.43	±0.43	±0.43	±0.98
Class II Div. 2	Mean	104.94	109.50	110.52	110.63	108.83
N = 12	S.E.	±0.84	±0.84	±0.84	±0.84	±1.92
Stages	Mean	106.77	112.03	112.97	113.30	111.27
	S.E.	±0.31	±0.31	±0.31	±0.31	±0.31

b) Anterior Upper Face Height (mm)

Angle Classification		Stage A	B	C	D	Classes
Class I	Mean	48.23	49.79	50.02	49.88	49.48
N = 29	S.E.	±0.33	±0.33	±0.33	±0.33	±0.52
Class II Div. 1	Mean	47.83	50.53	51.10	51.76	50.31
N = 46	S.E.	±0.26	±0.26	±0.26	±0.26	±0.42
Class II Div. 2	Mean	48.94	50.94	51.00	51.31	50.55
N = 12	S.E.	±0.51	±0.51	±0.51	±0.51	±0.81
Stages	Mean	48.33	50.42	50.71	50.98	50.11
	S.E.	±0.19	±0.19	±0.19	±0.19	±0.30

c) Anterior Lower Face Height (mm)

Angle Classification		Stage A	B	C	D	Classes
Class I	Mean	62.45	64.92	65.43	65.49	64.57
N = 29	S.E.	±0.36	±0.36	±0.36	±0.36	±1.07
Class II Div. 1	Mean	60.68	63.98	64.62	64.99	63.57
N = 46	S.E.	±0.29	±0.29	±0.29	±0.29	±0.82
Class II Div. 2	Mean	58.00	60.31	60.75	60.44	59.87
N = 12	S.E.	±0.57	±0.57	±0.57	±0.57	±1.61
Stages	Mean	60.38	63.07	63.60	63.64	62.67
	S.E.	±0.21	±0.21	±0.21	±0.21	±0.60

TABLE XXIX

Effects of Stage and Angle Classification

a) Ramus Length (mm)

Angle Classification		Stage A	B	C	D	Classes
Class I	Mean	43.04	45.08	46.12	46.10	45.09
N = 29	S.E.	±0.39	±0.39	±0.39	±0.39	±0.70
Class II Div. 1	Mean	41:70	45.08	46.02	47.34	45.03
N = 46	S.E.	±0.31	±0.31	±0.31	±0.31	±0.56
Class II Div. 2	Mean	42.69	46.31	47.06	48.44	46.12
N = 12	S.E.	±0.61	±0.61	±0.61	±0.61	±1.09
Stages	Mean	42.48	45.49	46.40	47.29	45.42
	S.E.	±0.22	±0.22	±0.22	±0.22	±0.40

b) Perpendicular Posterior Lower Face Height (mm)

Angle Classification		Stage A	B	C	D	Classes
Class I	Mean	48.59	50.75	51.81	51.63	50.69
N = 29	S.E.	±0.43	±0.43	±0.43	±0.43	±0.74
Class II Div. 1	Mean	47.37	50.93	51.91	53.01	50.81
N = 46	S.E.	±0.34	±0.34	±0.34	±0.34	±0.74
Class II Div. 2	Mean	48.00	51.44	52.94	53.81	51.55
N = 12	S.E.	±0.67	±0.67	±0.67	±0.67	±0.74
Stages	Mean	47.99	51.04	52.22	52.82	51.01
	S.E.	±0.25	±0.25	±0.25	±0.25	±0.42

c) Mandibular Length (Wylie) (mm)

Angle Classification		Stage A	B	C	D	Classes
Class I	Mean	100.32	104.08	104.89	104.80	103.52
N = 29	S.E.	±0.49	±0.49	±0.49	±0.49	±1.08
Class II Div. 1	Mean	96.89	100.89	101.90	102.75	100.60
N = 46	S.E.	±0.39	±0.39	±0.39	±0.39	±0.85
Class II Div. 2	Mean	94.00	97.44	98.25	99.56	97.31
N = 12	S.E.	±0.76	±0.76	±0.76	±0.76	±1.67
Stages	Mean	97.06	100.80	101.68	102.37	100.48
	S.E.	±0.28	±0.28	±0.28	±0.28	±0.62

TABLE XXX

Effects of Treatment and Stage

SNB ($^{\circ}$)

Treatment		Stage A	Stage B	Stage C	Stage D
Non-Extraction	Mean	76.54	77.03	77.35	77.37
N = 34	S.E.	±0.15	±0.15	±0.15	±0.15
Extraction	Mean	76.04	75.57	75.72	75.93
N = 53	S.E.	±0.12	±0.12	±0.12	±0.12

Significant at the 1% level