A CEPHALOMETRIC STUDY OF LATE MANDIBULAR GROWTH AND LOWER INCISOR POSITION FOLLOWING ORTHODONTIC TREATMENT

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This paper submitted in partial fulfillment
of the requirements for Certificate in Orthodontics,
Oregon Health Sciences Universtiy

June, 1986.

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank all of the people who have made my time in Portland fruitful, enabling me to pursue a career in orthodontics.

First of all, I wish to thank Dr. Buck, who made it all possible. I would like to thank the faculty members, particularly Dr. Doyle, for his patience, and Dr. O'Brien, for his insistence that I learn to observe rather than rely on the opinions of others. I would also like to thank my classmates, Viv, Tom, and Bart, for their support and friendship.

In doing the research for this paper and in writing it, Dr. Baumrind's assistance was greatly appreciated, as was the technical information provided by his office staff and the generosity of his family.

Lastly and most importantly, I would like to thank my husband, Gary, for his understanding and thoughtfulness throughout the past months.

CONTENTS

INTRODUCTION

Post-retention onset of mandibular anterior crowding in young adults is a frequent, disappointing observation. Theories abound as to the cause and include mesial pressure from third molar eruption, expansion or contraction of intercanine width, excessive function on lower canines in lateral excursions, changing lower arch form, inadequate retention, failure to place incisors upright over basal bone, persistence of oral habits, improper swallowing patterns or muscular imbalance, lack of periodontal fiber adaptation, lower incisor shape, tooth size discrepancies, poor occlusal interdigitation, and late mandibular forward growth. In accordance with these postulated causes, numerous clinical guidelines have been established, and even these do not guarantee the stability of an apparently well treated result. Undesirable post-treatment change or "relapse," particularly of the lower incisors, is something all orthodontists have experienced, regardless of the care that has gone into diagnosis and treatment.

In viewing treatment results, Horowitz and Hixon have raised the question: "How realistic is this definition of relapse when some of the post-treatment changes are biologic in nature?"[1] They have defined two forces in post-treatment change: (1) physiologic recovery or return toward the patient's original condition, and (2) normal developmental and dentitional changes that occur throughout the growth period and into adulthood. These late facial growth or maturational changes have been recognized as contributing factors in relapse.

The purpose of this investigation is to determine if comparison of cephalometric records taken at the end of treatment and following removal of retainers will show significant changes with respect to late mandibular growth and incisor position changes which could contribute to relapse crowding. Of particular interest is the possibility of "up-righting" changes in the lower incisors to produce a "distal drift" of the anterior segment.

LITERATURE REVIEW

Throughout the history of orthodontics, the problem of maintaining a stable result has been recognized. In 1919, Hawley[2] stated "If anyone would take my cases when they are finished, retain them and be responsible for them afterward, I would gladly give them half the fee." Early clinicians realized what a difficult problem relapse could be, and research has not provided an absolute set of cause and effect relationships or a certain solution. Evaluation of cases after short periods free of retention may lead investigators to miss changes of major importance that later become obvious.

In case follow-up at the University of Washington, it was found that as the post-retention observation period was extended from one to ten years, and as the sample size increased, greater instability and individual variation were seen.[3]

The reported incidence and severity of long term post-retention crowding varies. In a study of extraction and non-extraction cases, 12 to 35 years out of retention, Udhe and co-workers[4] reported a mean deficiency of 1.20 mm in Class I cases, 1.14 mm in Class II cases with extraction, and 1.11 mm in Class II non-extraction cases. Mandibular intercuspid width tended to decrease to or past the original width in all groups, with no significant difference between sample groups. Multiple regression analysis of all the factors considered in treatment and post-treatment changes could only account for 41 percent of the variability seen. This left 59 percent of the variability in lower anterior return of crowding unaccounted for.

Little and co-workers [3] reported on relapse of mandibular anterior alignment in 65 edgewise treatment, first premolar extraction cases, ten or more years post-retention. They found prediction of long term results impossible with pre-treatment and end-of-treatment model data. There was considerable variation, although arch length and width tended to decrease in spite of treatment constriction or expansion.

There was no association with net change in intercanine width or arch length reduction in treatment with relapse crowding in the post-retention period. Cases with good alignment or minimal crowding initially tended to become more crowded while severe crowding usually improved with treatment. Altogether, 70 percent of those patients were judged to have unsatisfactory lower incisor alignment, or more than 3 mm of irregularity, at evaluation.

Dewel[5] viewed lower anterior crowding in treated and in untreated dentitions as perhaps a normal and typical occurance.

> The reasons are not clear, but a moderate amount of crowding of the lower anterior teeth is possibly characteristic and typical of the human dentition . . . relatively few non-orthodontic normal occlusions present perfect alignment of the six lower anterior teeth. . . Further evidence of the persistence of this irregularity may be seen in the moderate relapses that occur occasionally even in cases in which extraction has been a necessary and basic part of treatment. Further advances in orthodontic knowledge are necessary if relapses are to be eliminated entirely.

Numerous longitudinal investigations on development of the dentition have shown that the young permanent dentition is characterized by small changes in arch width and some decrease in arch length. The decreased mandibular arch length and intercanine width reported by Little and co-workers may normally occur as studies carried beyond adolescence indicate that lower arch length in orthodontically untreated individuals may decrease into the third decade or beyond, and that arch width, particularly intercuspid width, may also be diminished. Subsequent to these changes, lower anterior crowding increases with age, at least into the early adult period.

Brown and Daugaard-Jensen[6] evaluated casts of 40 individuals from about 13 years of age to about 21½. Arch length decreased an average of 1.6 mm in the lower arch with a range of +0.4 to -4.7 mm. Crowding increased in 11 arches and remained the same in 13.

In a longitudinal study of 51 children using 528 serial casts, Barrow and White [7] reported little intercanine width change from three to five years, a very rapid increase from five to eight or nine years of about 4 mm in the maxillary arch and 3 mm in the mandibular arch, and in most instances a decrease of 0.5 to 1.5 mm in both arches after 14 years. Arch length was found to decrease 0.2 mm in the maxillary arch and 2.2 mm in the mandibular arch from 4½ to 13½ years.

They reported that in many cases arch length continued to decrease through 17 or 18 years of age and attributed this to (1) closure of anteroposterior interproximal space with permanent tooth eruption, (2) lingual tipping of anterior teeth, and (3) wear at all proximal contact areas. Barrow and White also found crowding to be more pronounced in the mandible than in the maxilla. Spacing present at three years was gone at seven, and after seven, crowding started and increased to "1/3 incisor width" by 15 years. From 6 to 14 years of age, incidence of crowding increased from 14 to 51 percent of the cases.

Moorrees[8] published an extensive study based on longitudinal data collected on 184 white children observed over a 12 to 15 year period, starting at age three. Among other things, he evaluated arch breadth and arch circumference in those children with normal alignment at 18, or 1/3 of the total sample. Mandibular intercanine distance was found to increase continually after five years to a maximum at ten years of age for males and nine for females. At around the mean age of emergence of the permanent canines, intercanine width decreased slightly with little change after 12 years. Arch circumference data was obtained at the ages of 5 and 18 only. The mean circumference of the mandibular arch was found to be less at 18 than at 5. Males showed an average decrease of 3.39 mm and females an average decrease of 4.48 mm. The maxillary arch, on the other hand, showed a small mean increase for both sexes. Crowding and spacing changes were also evaluated, with "normal" considered to fall within a range of 3 mm of crowding or spacing. Although none of the cases evaluated to determine mean growth patterns showed crowding at 18, there was a decrease in spacing in the time period prior to eruption of permanent incisors to the time last records were taken.

Knott[9] reported on 29 Iowa children with "good occlusion." She followed these children from the age of 9 to 15, 16, or 17. She found little change in arch width after age 13 in either males or females, but found arch length to decrease in both arches for both sexes. Mean mandibular length decreases were 1.4 mm for males and 1.0 mm for females.

Sillman[10] studied dimensional arch changes from birth to 25 years of age in 65 normal white subjects. He evaluated anterior and posterior components of arch length by measuring from the interproximal contact of the centrals to the distal of the canine, from the distal of the canine to the distal of the second primary molar or second premolar, and from the primary molar or premolar to approximately the distal aspect of the alveolus of the second molar. Additionally, he evaluated arch width and graphically presented the composite mean pattern for maxillary and mandibular arch changes in males and females.

From his composite drawings of length and width changes for each sex, it can be seen that arch length from incisors to canines decreases in the mandible and maxilla in both males and females after age 12, as does intercanine width. Although the author reported no statistically significant change in anterior arch length in either sex for the mandible after the age of 10, the graphic mean representations show that in females, anterior arch length at 20 is less than at age eight, and in males, it is less than at age 16. Mandibular intercuspid width in both sexes also showed slight decreases after reaching maximum dimensions at age 16.

Cryer[11] surveyed 1,000 London school children in a serial study between the ages of 11 and 14. He found that 62 percent had crowding of the lower anterior segment at 14 and in 50 percent of these cases, the crowding had increased in the three preceding years.

Lundstrom[12] evaluated crowding and spacing of teeth with age in his longitudinal work with twins evaluated during adolescence and as young adults. Sixteen of 19 showed a mean mandibular arch length decrease of

1.6 mm while the rest showed no change. Mean molar and premolar arch widths showed almost no change.

Lundstrom gave possible etiologies for the arch length decrease, including loss of leeway space with eruption of the premolars and decreased tooth width through caries or abrasion, although in many subjects he felt the changes were not due to these factors or to the presence of third molars. He ultimately concluded that the decreases seen were due to a mesial migration of the posterior segments, or possibly to retroclination of the incisors.

De Kock[13] examined 10 males and 16 females previously studied from the ages of 12 to 17 in the Iowa growth project in a follow-up study at a minimum age of 23. For every person in the study, he found that arch depth decreased after the age of 15. The mean decrease in mandibular arch depth from 12 to 26 was 3.2 mm for males and 2.6 mm for females. For males and females, the percentage of arch length decrease from 12 to 15 was 6 and 4.5 percent respectively. The decrease from 15 to 26 was 4 and 4.2 percent respectively.

Sinclair and Little[14] evaluated casts of 65 untreated normal occlusions from the Burlington Growth Center Study to determine maturational processes between the mixed dentition, early permanent dentition, and adult dentition stages.

Total mandibular arch length was found to decrease significantly for for males and females between the first and second and between the second and third sets of records. Both sexes showed a significant decrease in intercuspid width between the mixed dentition and adult stages. Changes in males were found to be more gradual over the period of the study, while in females, intercanine width changes were greatest between early permanent and adult dentition stages.

Both males and females showed a significant increase in incisor irregularity during the permanent dentition interval. Females had significantly more incisor irregularity than males with 3.13 ± 1.75 mm versus 2.28 ± 1.44 mm at the final evaluations, done at a minimum age of 17 for females and 18 for males. Twenty-two females and 21 males, or 66 percent of the sample, showed an increase in incisor irregularity betwen the last two stages.

No correlations of clinical significance were found between any of the parameters evaluated, suggesting an independence of the changes seen in the cast evaluations according to the authors.

In comparing this group to the treated Class I extraction cases from the post-retention group presented by Little and associates,[3] the authors found that the arch length decrease was virtually identical in both groups, while lower arch cuspid width decreased three times as fast and incisor irregularity increased twice as fast in the treated group. Overbite and overjet increased in the treated group and decreased in the untreated sample.

Decreased mandibular arch length and increased anterior crowding with age is almost universally agreed upon in the preceding reviews of longitudinal growth studies. Several causes for these changes have been put forth, but the one of primary interest here is late facial growth change with dental compensation at the lower incisors, producing post-adolescent crowding.

Numerous authors have commented on decreased facial convexity with age, a relative retrusion of the denture with respect to the nose and chin, in post-adolescent and young adult subjects. Nose growth and late mandibular growth contribute to this effect. A possible consequence of this late mandibular growth pattern may include forcing the mandibular denture into the maxillary incisors and the restraining facial musculature which would seem to cause lower incisor retroclination or uprighting. Repositioning the lower incisors in this fashion would decrease arch length and result in crowding.

The direction of mandibular growth may also play an important role in compensatory eruption or positional changes in the lower incisors. Addition of orthodontic treatment factors to the normal growth changes further complicates the problem.

Reidel[15] and Moore[16] describe possible consequences of late mandibular growth with respect to lower incisor position. Moore writes:

> The occurence of crowding of the mandibular incisors in young adults or late teenagers has often been blamed upon the eruption of the mandibular third molars. Another possible explanation could be based upon differential growth of the facial growth sites. If mandibular condylar growth continues after bone growth at the maxillary tuberosity has ceased, a change in the relative anterior-posterior position of the maxilla and mandible may occur. The relative forward movement of the mandible will carry with it the mandibular denture which is still occluding with a maxillary denture that is not being carried forward with growth. The maxillary denture through muscle tension could conceivably restrain the mandibular anterior teeth as they are being carried forward and produce crowding of the mandibular incisors.

In a discussion on muscle activity, oral malformation, and growth changes, Subtelny and Sakuda[17] described the tongue as the dominant force in shaping the lower arch in early developmental stages. With maturation, the influence of the lip musculature was felt to increase. Subtelny and Sakuda theorized that this occurred because of the mandibles' frequent increase in size up to a fairly late age, allowing it to cradle the tongue and to permit the lips to exert a greater pressure on the teeth. The mandible could be thought of as out-growing the lip musculature with production of lingually directed forces uprighting the incisors and decreasing intercanine dimension. This influence, combined with a mesially directed component of force in the buccal segments, would force crowding of the lower incisors with late growth changes.

Studies on bone remodeling in the mandible have consistently shown that the anterior portion of the alveolus is not an area of bony apposition, but rather a resorptive field that decreases in size with age. These findings would lend credence to theories of lower incisor uprighting or retroclination, the effects of which would be accentuated by appositional chin growth.

Enlow and Harris[18] sectioned and stained 25 adult human mandibles obtained from cadavers or purchased from anatomical supply houses. Although individual anatomy and resorptive patterns were variable, the labial surface of the mandibles in the intercanine area was resorptive in nature and flattened, showing endosteal apposition, while the lingual surface showed periosteal growth and endosteal resorption. The labial cortex of the chin was quite variable, some showing periosteal addition and others with resorptive areas over the entire chin surface.

Kurihara, Enlow and Rangel[19] sectioned and stained maxillas and mandibles from 36 dry skulls ranging in age from newborns to about 14 years to determine when outer surface resorptive fields became evident.

They concluded that the outer surface of the entire mandible was appositional in nature until after the eruption of the second deciduous molar when resorptive fields became evident in the anterior alveolar region. These fields spread progressively in varied patterns with age.

When resorptive fields appear in the anterior areas of either maxilla or mandible, anterior growth elongation of the bony arches ceases except for small increments occurring with incisor eruption. These findings support the logitudinal studies of Sillman and Moorrees, which show early establishment of anterior arch length.

Siatkowski[20] presented a mathematical investigation of incisor uprighting correlating data from growth studies done by Bjork and Sillman. Changes in mean incisor axial inclination during late growth described by Bjork were related to changes in mean anterior arch dimension from Sillman's longitudinal sample to determine relationships between the two. Additionally, he applied the analysis thus developed to untreated individuals followed longitudinally.

He found that incisor uprighting as reported by Bjork[21] in a non-implanted cross-sectional cephalometric study of boys and adult conscripts was sufficient to account for the decreases in anterior arch length reported in Sillman's longitudinal male and female sample, without considering mesial drift or bodily incisor movement. In an evaluation of 18 males and females with untreated Class I occlusions from the Forsythe Dental Center, he found the interincisal angle to decrease in all cases and the anterior arch length to decrease in all but two arches. For all except one case, the predicted interincisal angle change needed to match anterior arch decreases based on tipping around the centers of resistance for the upper and lower incisors agreed with the interincisal angle to within ± 2 degrees.

Clinical longitudinal studies have not totally supported the previous theories on lower incisor position relative to late mandibular growth, although most investigators agree that facial convexity decreases with age. Early cephalometric evaluations of untreated individuals seem to bring out variation in lower incisor angulation, rather than a consistent pattern of change. Later studies stress the effects of mandibular growth direction on incisor inclination.

Schaeffer[22] evaluated upper and lower incisor axis change with growth using serial cephalometric films of 47 untreated Class I and Class II occlusions primarily from the Bolton study. He found the mean lower incisor/gonion-gnathion plane to be fairly similar when calculated for each yearly age interval from 7 to 21, although the ranges tended to be quite large. This angle was found to increase, decrease, or remain stable with growth, as was the angle of the maxillary incisor to the palatal plane and the interincisal angle.

Although no correlation between the behavior of these angles was found and in spite of the behavior of their axes, the incisors were found to occupy relatively more posterior positions in respect to the maxilla and mandible with facial growth. Schaeffer observed that this might account for esthetic improvements of dentally prognathic children with time.

Lande[23] studied growth related changes in profile using 34 series of laterial cephalometric films primarily from the Bolton study. All were untreated males with a mean age span of 4.4 to 17.1 years for the sample of 509 head plates. Data was analyzed from 3 to 7, 7 to 12, and 12 to 18 years. He found that the mandible tended to become more prognathic, which usually occurred after age 7, while the maxilla did not. Inclination of the lower border of the mandible decreased as prognathism increased. Alveolar forward growth, as measured by changes in A and B points, did not keep up with horizontal skeletal base growth, and facial convexity decreased in nearly all cases.

In a serial cephalometric study of growth from age 8 to 17, Brodie[24] described "late growth changes:"

> The late stages of growth have been shown to be accompanied by a continuation of forward and downward movement of the anterior nasal spine and of pogonion, while the dental arch and its supporting bone tends to move more slowly and thus drop behind. This decreases the prominance of the denture. At the same time, however, such behavior is not necessarily accompanied by a more upright position of the incisors. These teeth may become less procumbent, more procumbent or may remain at their original axial inclination.

Brodie stressed "marked consistency and stability of the individual pattern" of the face with growth, but found considerable variation in the behavior of the incisors.

Bjork and Palling[25] examined nonimplanted serial cephalometric films of 243 Swedish boys between the ages of 12 and 20 years. The interincisal angle was found to increase with age, but not significantly. Individual changes were found to vary from proclination to retroclination, supporting Shaeffer's work, although variation was less at age 12 than at age 20.

Generally, they found that the mandible became more prognathic, the profile flattened, and the mean lower incisor change was a retroclination of 1.7 ± 0.29 degrees to the mandibular line.

In a longitudinal cephalometric study of 25 pairs of twins from the age of 12 to 15 to 23 to 26 years of age, Lundstrom[26] attempted to correlate horizontal or vertical growth of gnathion to changes in incisor inclination, overjet, overbite, and crowding. He found that a vertical growth direction of gnathion was combined with proclination of the lower incisors while horizontal growth movement produced the opposite effect, possibly due to the effects of the tongue or the perioral musculature respectively. Vertical growth of gnathion tended to open the mandibular plane angle; horizontal growth tended to close it.

No association was found between growth direction and overbite, although horizontal growth seemed to decrease overjet and vertical growth to increase it.

There was no indication that an anterior growth pattern of the mandibular base was associated with late onset mandibular anterior crowding.

Richardson[27] evaluated lower arch crowding in 51 subjects (29 female and 22 male) at ages 13 and 18, using models and 60 degree rotated right and left cephalometric films. All subjects had both lower third molars and no lower arch orthodontic treatment. She found that over this five year span there were statistically significant increases in lower arch crowding, forward movement of the first molars, slightly increased intermolar width and proclination of the lower incisors.

Leighton and Hunter[28] compared longitudinal cephalmometric records for individuals with lower arch spacing, moderate crowding, and severe crowding, and concluded that crowded dentitions "exist in a morphologically distinct supporting structure" characterized by downward growth and deficient anterior growth resulting in a shorter mandibular corpus. These faces were characterized by steep mandibular and occlusal planes and shorter posterior face heights, although anterior face height compared favorably to that of the uncrowded group.

Prior to Bjork's implant work, all cephalometric superimposition studies had been done using cranial base structures or reference planes using different cranial base or dental arch reference points. For superimposition to evaluate within arch treatment or growth changes, the mandible or maxilla was usually superimposed to give a "best fit" of two different tracings. Using these sorts of comparisons, early investigators detected little change in mandibular morphology with growth, which was universally described as downward and forward movement of both the mandible and maxilla with constancy in mandibular morphology and vertical eruption of teeth.

Bjork's cephalometric superimposition technique involved placement of metallic implants in both jaws and using these for orientation to determine growth changes in long term logitudinal studies. These studies revealed tremendous variation in growth direction, rotation and remodeling changes in the mandible with growth, and compensatory eruption of the teeth with respect to growth direction.

Manidibular length was found to increase primarily by growth at the condyles.[29,30] Generally, growth was directed slightly forward of the inclination of the ramus, following an anteriorly curved path. Large individual variation was seen with a range of 45 degrees from the mean in adolescence.[31] The direction of this growth was found to influence the shape of the mandible, with upward growth increasing vertical height and backward growth increasing sagittal length.[29]

Superimposition of the mandible in serial cephalometric films on the metallic implants showed rotation during growth. The mandible did not simply increase in size by resorption and apposition along the same morphological pattern, but rather showed rotational changes based on the direction of growth at the condyle. This rotation was almost completely masked by remodeling along the lower border, ramus, and gonial angles[32] when "best fit" superimposition methods were used. In other words, the external morphology of the mandible remained the same due to the remodeling changes while the bone was found to rotate along a curved path during growth.

Rotational changes were found to be strongly correlated with the direction of condylar growth as were the paths of tooth eruption.[32] In cases of vertical or anteriorly directed condylar growth, there could be anterior rotation of the mandible around a fulcrum point at the lower incisor edge or at the premolars, with all teeth erupting mesially.[30,32] With sagittal or posteriorly directed growth, the anterior teeth erupted distally while the posterior teeth tended to erupt vertically.[30] In these instances, there was backward growth rotation with the center at the occluding molars.

In cases of forward growth rotation, considerable mesial migration of the dentition with marked proclination of the lower incisors was found to occur between the ages of 7 and 20 relative to mandibular implant lines.[33] When comparing lower incisor inclination to the lower border of the mandible, almost no change could be detected.[33]

In nine forward rotating cases described in detail, mean forward molar migration was 5.2 mm, while the incisor migration was 3.2 mm, shortening the arch by 2.0 mm.[33]

Backward mandibular growth rotation was found in very few cases examined by Bjork and co-workers. These individuals tended to show a backward tipping of the lower incisors leading to anterior segment crowding.

Overall changes reported in lower incisor positions in growing individuals appear to depend on the type of cephalometric superimposition methods employed, and whether these take growth rotation into account. Theoretically, facial musculature may also play an important role.

Treatment-related changes may also effect lower incisor position on a long term basis. Increasing incisor procumbency during treatment and post-treatment changes in axial inclination have been implicated in lower incisor relapse, although the relationship to mandibular growth is not completely clear and has been considered by few investigators.

Mandibular arch length has also been shown to decrease in treated cases as well as in untreated individuals with age, as has facial convexity, which would tend to support to some extent the possiblity of lower incisor uprighting.

In cephalometric evaluation of numerous non-extraction cases, Brodie[24] and co-workers found that disturbance in the axial inclinations of teeth during orthodontic treatment tended to be self-correcting following treatment.

Tweed[35] placed strong emphasis on lower incisor position, stressing that the incisors should stand upright relative to the body of the mandible for optimum treatment stability and esthetics, although he did not present any material on the possibility of relapse crowding in individuals treated to this ideal.

Margolis[36] presented several cases illustrated with composite photographs--lateral cephalometric radiographs. He advocated a "vertical" position of the lower incisor to the mandibular plane, as did Tweed, for optimum results. He felt that if incisors were proclined in treatment, they would tend to move upright to their original positions with subsequent crowding.

Nance[37] felt that the "mandibular teeth ultimately come to positions where they are in equilibrium with the forces upon them." In most instances labial movement of the lower incisors in treatment to gain arch space was described as "suicide," with the ultimate result of anterior segment collapse due to muscle force imbalance.

Cole[38] evaluated 21 first premolar extraction cases cephalometrically at least one year free of retention. He found a strong tendency for lower incisor inclination to return to pretreatment relationships. Eleven cases tended to return to their original inclinations, six remained stable, and four continued to move in the direction of treatment. Even in cases where a tendency to return to the original inclination was shown, he felt extraction was successful in "establishing a more vertical position of these incisors and their alveolar processes in relation to their mandibular planes."

Litowitz[39] evaluated 20 successfully treated malocclusions from the graduate department at the University of Illinois. All were treated without extraction, and in some cases the lower arch was expanded up to 12 mm. Tracings were made from lateral headplates taken at the beginning and end of treatment and one to five years after the removal of all retention devices. He found that overbite tended to return to pretreatment levels, arch expansion was generally unstable, and that the lower incisor exhibited a variety of changes. In cases where treatment resulted in an increase in the axial inclination of the lower incisor to the mandibular plane, half tended to regain their inclination and half became more procumbent. Where treatment decreased the axial inclination, most cases continued to decrease after retention.

Baum[40] stressed sex differences in profile changes. In a study of age and sex differences with respect to dentofacial changes, he found that the denture of the male patient would "retreat" into the face a greater amount than in females after completion of treatment. He theorized that females were more "developed" at a given age than males and thus had flatter or more adult-type profiles than did males prior to treatment.

In a post-treatment evaluation of 45 patients without relapse tendency an average of three years after completion, Baum[41] described "longer, later and larger" chin and nose growth in the males with a resultant retrusion of the denture or an advancement of the nose and chin. He felt that as the male face matured, mandibular growth would continue beyond that of the maxilla, bringing the chin and lower teeth forward into "strong functional contact" with the upper incisors, resulting in upper spacing or lower anterior crowding.

Subtelney and Sakuda[17] evaluated changes in the dentition using lateral cephalometric films and models for three groups of individuals: untreated controls from the Bolton study, treated individuals with "late growth changes" apparent as crowding in the lower arch, and treated individuals who maintained good lower arch form into adulthood. They found interincisal relationships became more upright in all groups between adolescence and adulthood. In those individuals with late growth changes, the lower incisors were described as more procumbent initially and at the end of treatment and although they showed considerable uprighting after treatment, they were still more procumbent at final analysis than incisors in the other groups. The authors felt that inability to upright these teeth may have been due to differences in mandibular growth.

Fastlicht[42] considered crowding in mandibular incisors comparing treated Class II, Division 1 cases 1½ to 10 years after retention and untreated cases selected for well-aligned upper arches. He reported correlations between age and crowding and overbite and crowding. In the treated and untreated groups, the correlation between age and crowding was .347 and .288 respectively. The correlation between lower arch crowding and overbite in the untreated cases was .283. Thus, as age and overbite increase, crowding increases, although correlations are not strong.

Fastlicht assumes that increase of overbite increases mandibular anterior crowding because mandibular incisors are moved more lingually than upper incisors are labially, due to the position of the upper incisor cingulum and the greater crown and root size of the upper incisors. He felt incisor crowding or recrowding was an anatomic-physiologic phenomenon of dental adaptation.

Miller[43] compared control and treated patients to determine the long term effect of orthodontic treatment on lower incisor position. Initial records for 19 treated and 27 untreated patients were taken at a mean age of about 12 years, and final or post-retention records at a mean age of about 19 or 22, respectively. Treatment was completed at a mean age of 15 years 10 months; to be included in the study, these patients were required to have had lower incisors positioned at least 3 mm lingually during treatment and to have been free of retaining devices for three years.

Miller found that in the non-treated control group, lower incisors moved lingually 0.3 mm and in the treatment group, the incisors were positioned 5.2 mm lingually from their original position with 0.4 mm "rebound" on the average. The ranges and standard deviations were large and similar between groups, indicating individual variation. In spite of lingual positioning and adequate space during treatment, average lower incisor relapse crowding was over 2 mm in the treated group.

Schudy[44] studied post-treatment craniofacial growth in 74 Caucasians using cephalometric evaluation 1 to 5.4 years after completion of treatment. He concluded that the mandible grew forward more than the maxilla during this period, that condylar growth was predominantly vertical, and that the SN-mandibular plane, SN-occlusal plane, ANB, and gonial angles tended to decrease. The profile became less convex due to forward movement of the chin and growth of the nose.

Schudy elaborated on differences in growth between individuals with high mandibular plane angles (greater than 37 degrees) and low mandibular plane angles (less than 26.5 degrees). Although mean total condylar growth was virtually the same in both instances, he found that in high angle cases, linear condylar growth had a fairly large horizontal component, while in low angle cases, growth was nearly all vertical. The horizontal component of growth in the high angle group resulted in a forward positioning of pogonion separate from mandibular rotation. This forward component of movement was countered by a greater vertical face height increase to result in a similar forward movement of pogonion in high and low angle cases. In low angle cases, forward mandibular rotation (decrease in SN-mandibular plane angle) brought pogonion forward and was countered by smaller increases in anterior face height. Lower incisors were found to move (tip) lingually to a much greater degree in low angle cases, which were found to have 23 percent more overbite relapse than high angle cases.

Schudy's criteria for including cases in this investigation included cephalometrically demonstrable condylar growth changes. He felt incisor uprighting to be largely a result of functional forces bearing on the teeth as the mandible moves forward with growth.

Schudy's work differs from Bjork's in that in the flat mandibular plane, anteriorly rotating cases had lingual tipping of the incisors, while Bjork describes these cases as showing proclination of the incisors.[31] Schudy's conclusions do support Lundstrom's[26] findings with respect to condylar growth direction and lower incisor inclination.

In a a study of 80 cases at least ten years post-retention, Shapiro[45] reported that mandibular arch length decreased substantially in all patient groups during the post-retention period. Cases were either Angle Class I or II and extraction or non-extraction. No reference to age or sex was made. Non-extraction cases lost a mean of 2.6 mm and extraction cases lost a mean of 3.1 mm.

Schulhof and co-workers[46] studied 78 sets of records for treated patients four years or more post-retention and 82 sets of records of individuals with normal, untreated occlusions. In the treated group, there was no significant difference in relapse crowding between those patients whose incisors were moved lingually, labially, or held in the same position. Additionally, there was also a lack of correlation with respect to incisor position relative to cephalometric planes such as APo, NB or mandibular plane and relapse crowding.

Shields and co-workers[47] assessed 54 first premolar extraction cases treated with traditional edgewise mechanics at least ten years post-retention. Mean ages at end of treatment and follow-up were not given, although 46.39 percent were Class I, 44.4 percent Class II, Division 1, and 9.3 percent Class II, Division 2. Cephalometric superimpositions were made by registering on the inferior alveolar canals, inner contour of the symphasis, and unerupted third molars.

They found that on a long term basis, lower anterior alignment was upredictable with respect to cephalometric paramaters including incisor inclination, horizontal and vertical growth, and mandibular plane angle, in contrast to Schudy's[44] findings. Only a slight tendency was noted for incisor inclination to return toward pretreatment values.

The preceding review has failed to show a predictable pattern of change in lower incisor position in the post-retention period which does not seem to support a theory of incisor uprighting with age secondary to late mandibular growth, although Schudy's treatment group appears to be an exception with respect to low mandibular plane angle cases.

Another major question concerns cessation of facial growth. Although the majority of growth is complete in post-retention age individuals, is there significant capacity left for facial growth and compensatory tooth position changes in individuals who are "adults" or who are over 18? Most of the large longitudinal growth studies were done on individuals up to this age, and in cases when it was carried further, no direct observations were made on the relationship of mandibular growth to lower incisor crowding in the late second and early third decades. A few have considered this question, but no trend has been established.

Forsberg[48] evaluated 25 males and 24 females longitudinally from 24 to 34 years of age using lateral cephalometric head films. He found changes in bony profile and face height due to posterior mandibular rotation and an adjustment of the upper incisors to this new lower jaw position. Soft tissue changes included nose growth anteriorly and lip retrusion. Forsberg attributed this rotation to eruption of the posterior teeth with a vertical increase in bite.

Forsberg did not describe lower incisor position changes in great detail, but did find that the lower incisor became significantly more procumbent relative to the mandibular plane in the male group. He did not note changes in spacing or crowding.

Sarnas and Solow[49] evaluated changes in skeletal and soft tissue profile in 50 female and 101 male Swedish dental students longitudinally from 21 to 26 years of age using lateral cephalometric films. They were able to show only small mean changes in most of the variables evaluated, and in most cases measurement error was larger than mean change, which was on the order of magnitude of 1 mm or 1 degree. Total anterior face height did show a significant change of about 1.5 mm increase in males and 1.25 mm increase in females. Incisor position changes were almost non-existant, as were changes in the relationship of the nose, lips, and chin during the age ranges evaluated by this study.

MATERIALS AND METHODS

The sample evaluated in this study consisted of 31 Caucasians, 6 males and 25 females, with Angle Class I malocclusions that were treated in the Department of Orthodontics at the Oregon Health Sciences University. These individuals were predominantly first premolar extraction cases, treated with standard banded .022 edgewise appliances. Prior to any treatment, individuals were implanted with six tantalum-tungsten implants using the techniques outlined by Bjork.[29,30]

Implants were placed on the right side only with three in the maxilla and three in the mandible. Mandibular implants were placed approximately in the midline, mid-body beneath the first molar, and near the anterior border of the ramus, as shown in Figure I and described by Thorburn.[50]

Criteria for inclusion in the study sample was based on availability of lateral cephalometric radiographs at the beginning of treatment, at or within six months of debanding, and at the end of post-retention follow-up when the patient was dismissed from the clinic. (These events will be referred to in sequence as timepoints one, two, and three.) The minimum time span between the beginning of treatment and the end of follow-up was 3.38 years in those individuals comprising the sample, with a mean of 5.87 years and range of 6.10 years. Mean age, range, and standard deviation for the entire sample at each timepoint is given in Table I.

Angular and linear measurements of changes in the head film series for each individual were made with a computer aided analysis described by

Baumrind and Miller[51] and Curry[52], et al., using the timepoint one film as a reference film to which the subsequent films were compared.

The timepoint one film was pierced with ten reference holes, arranged in two parallel lines, using a size 17 dressmaker's pin in a pin vice. These were placed using a ¼ inch plastic template, mounted with 0.018 inch center drilled steel bushings. The template was placed over the film so as to encompass the areas of interest on the headplate. Subsequent films were marked in a similar fashion, with the exception that only the corner holes of the templates were pierced.

Two independent tracings were made by the same investigator for all three films in each individual's series using 0.003 inch matte acetate. Pierced reference points and the three mandibular implants were traced. The four corner reference points, designated as fiducial points A, B, C, and D were then used to register subsequent tracings of the same film for the computer aided analysis. Of the remaining holes on the reference film, the lowest pair, 11 and 12, were designated as left and right mandibular registration points, and were used to register mandibular changes in subsequent films. This was done by best fit superimposition of the timepoint two and three acetate tracings on the reference film implants, and then transferring the location of points 11 and 12 to the tracing of the comparison film.

Landmarks and registration points were then converted to digital form directly from the film or tracing, using a Summagraphics ID series digitizer with a transilluminated table, linked by a DIGIT program to a computer at the UCSF Computer Center via remote terminal. The following points were digitized in this order and are illustrated in Figure II.

A - Corner Reference Fiducial
B - Corner Reference Fiducial
C - Corner Reference Fiducial
D - Corner Reference Fiducial
1 - Sella
2 - Nasion
3 - Articulare
4 - Lower Incisor Edge
5 - Lower Incisor Apex
6 - Pogonion
7 - Mesial Cusp Tip, Lower First Molar
8 - Mandibular Implant (Most Distal)
9 - Mandibular Implant (Center)
10 - Mandibular Implant (Most Mesial)
11 - Left Mandibular Registration Point
12 - Right Mandibular Registration Point

After the tracings were successfully digitized, the information was passed to a program called AVEPIC. Using a least squares method, the digitized values of the tracing points for each film were mathematically superimposed based on the program's built-in representation of the corner fiducial reference points.

The computer calculated the linear distance between the built-in value for each of the corner fiducials and the best fit values for each tracing, and also the mean of these four distances for each tracing. If the mean distance exceeded 1.0 mm in any tracing or the range exceeded 0.3 mm for multiple tracings of one film, processing stopped. If all tracings "stacked" properly on the corner fiducials, processing continued.

At this stage, coordinate values for all digitized points were based on the corner fiducials with the origin at B and the x axis passing through C. Since point coordinates vary between films due to arbitrary template location, the x and y axes were redefined for each film with respect to the sella-nasion plane for that film. Duplicate tracings for each film were processed, averaging x and y values for sella and using the mean as the origin of a new coordinate system. Similar procedures were used with respect to nasion, designating the mean as a point on the x axis. All of the other previously digitized points were then redefined with respect to the new coordinate axes.

For each landmark, previous work by Baumrind and Frantz[53] has developed "characteristic envelopes of error." For the two tracings of each film, the AVEPIC program compared the distribution of the location points for each landmark with the envelope of error characteristic of that landmark. If variation was excessive with respect to the predetermined envelope of error, the landmark's location was rejected and it was redigitized so that two digitized locations for that landmark point fell within the program's acceptable range. The digitized values for the coordinates were then averaged to yield a single value for each point. These procedures were also followed for mandibular superimposition registration points (points 11 and 12).

If excessive error was detected in location of either the sella or nasion points, the processing for that film stopped and the entire film was redigitized, since establishment of sella-nasion oriented axes was not possible. If other points were rejected, only the corner reference fiducials and the outlying point had to be redigitized.

The final product of the AVEPIC program was an AVEPIC file containing the digitized information in terms of the sella-nasion based x,y axis location for all of the fiducial points, cephalometric landmarks, and mandibular registration points.

AVEPIC files were then loaded into a relational data base called INGRES, which stored the coordinate information. A COGO, or coordinate geometry program, was then used to compute two-dimensional linear and angular relationships between anatomic landmarks using the information from INGRES.

The resulting product was an SAS file, which put the data in a format compatible with a commercially available package which was used to evaluate the data.

For this study, data was manipulated by the computer to determine angular changes in the lower incisor's position in each individual's film series with respect to the occlusal plane of the timepoint one film. Tracings of timepoint two and three films were oriented on the mandibular implants of the reference film, and the occlusal plane determined for this film was transferred to the following ones in the series in a procedure analagous to transferring the Frankfort plane in standard serial cephalometric analysis. Data points used to define this angular relationship were the mesial cusp tip of the lower molar and the lower incisor edge for occlusal plane, and the lower incisor edge and apex for the long axis of the lower incisor. This information was reported in a "lower occlusal frame of reference," that is the mesial cusp tip of the first molar was redesignated as the origin of an x,y coordinate system within the mandible, and the lower incisor edge was designated as a point on the x axis for the occlusal plane of the reference film. This new coordinate system was also transferred to subsequent films using implant superimposition.

Additionally, the information was also used by the computer to make linear measurements. Mandibular growth was assessed by changes in mandibular length within each individual's series, defined as the distance from articulare to pogonion. Positional changes in the molar cusp tip and lower incisor edge were noted by changes in their coordinate position using the lower occlusal frame of reference.

Angular and linear data in all instances were noted at timepoints one, two, and three. Comparisons over time were made between timepoints one and two and between timepoints one and three.

Baumrind and Miller[51] describe two advantages in using the corner fiducial reference technique they have developed which is outlined in the preceding portion of the paper. First, use of four points surrounding the area of interest instead of two protects against rotational errors in landmark location. Second, permanently marking the fiducials on the film increases the reliability that can be achieved in relating subsequent tracings of the same film to the initial one.

Permanently marking the film could be viewed as a disadvantage, but this is done in areas that do not contain cephalometrically useful information. Baumrind and Miller[51] offer permanent reference marking of high quality photographic copies of the radiographs as a possible solution to this objection.

ERROR ANALYSIS

In any investigation using measurements based on cephalometric landmarks, three types of error must be addressed: radiographic technique errors or "errors of projection," errors in the precision with which landmarks are located or "errors of identification," and errors made in drawing lines between landmark points and making measurements.[53,54]

Projectional errors result from the film's two dimensional representation of the three dimensional skull. Enlargement occurs due to the nonparallel nature of the x-rays; there is foreshortening of distances between points not on the same plane and radial displacement of all items not on the central ray.[53]

Angular measurements made between points in the midsagittal plane are theoretically subject to the same enlargement factor avoiding error but positioning patients precisely in the cephalostat to produce coincidence between the patient's midsagittal plane and that determined by the machine is not possible, resulting in some distortion of angular measurements as well.[55] Linear measurements in the midsagittal plane are subject to enlargement and linear measurements using points outside this plane (such as the lower molar cusp tip or implant points) are also subject to the effects produced by foreshortening. These sources of error can only be completely controlled by the use of three dimensional landmark location obtained through use of stereo head films or combining information available in lateral and frontal films.[54,56]

Errors in landmark identification were quantitatively measured by Baumrind and Frantz.[53] They found in a study of tracings done at the

University of California, San Francisco, that errors in landmark identification were significant, varied between landmarks, and tended to form characteristic patterns or "envelopes of error" for each landmark. Ability to identify landmarks depended on the sharpness of the curve they were located on, the contrast of the surface with the surrounding areas, and the firmness of the point's technical definition.

The probability of locating one point more than two standard deviations away from its best estimate, as shown by the envelope of error characteristic for that landmark, was determined to be about 0.05: in other words, about 0.95 probability of successful location. If numerous points were located in any given tracing, the probability of correct location for all points was 0.95X, with X equal to the number of points located. Baumrind and Frantz[53] illustrate an example with sixteen points, so 0.95^{16} yields a 44 percent chance of correct location for all points. If a pair of tracings with these 16 points is used for comparison purposes, the chance of correct location of all points drops to .44 x .44, or 19.4 percent.

The solution to this problem is the use of replicate measures in the AVEPIC program. Two estimates for each point from the digitized values must be within the two standard deviation envelope of error for that landmark. If variation is excessive, the landmark must be redigitized so that two points are acceptable. The location of these is then averaged. In the above sample, the probability of the mean value significantly differing from the true value is the probability of erring from that value in the same direction for both estimates, or 0.025 x 0.025, or 0.625 percent. The chance of completing a duplicate single film sixteen point analysis without undetectable errors of two standard deviations or more becomes 98 percent.[53] For duplicate analysis of two different films, the chance of completion without undetectable error also increases to 98 percent.[53] These duplicate measurements and envelopes of error are also similarly applicable to the mandibular implants.

Errors in landmark location would obviously have a profound effect on angular and linear measurements. Also of importance is the fact that hand operations involving construction of lines and measurements with rulers and protractors add to this error, but can be completely eliminated through the use of the AVEPIC program to compute the linear and angular relationships of interest using the coordinate values of the landmarks involved.

Baumrind and Frantz[54] point out three considerations concerning the error in landmark location and its effect on angular and linear relationships involving that landmark: the magnitude of error involved in a given point's location, the distance between the points used to construct the line or angle of interest, and the angle at which the line between two landmarks points intersects the envelope of error for each of those points.

The closer two given points are, the greater the percentage of error in linear measurements for any specific amount of error and the greater the effects on angular errors. A line connecting two landmarks intersecting an envelope of error for a landmark will be subject to less error if it intersects the envelope in its narrower dimension, and more error if it intersects the envelope in its widest dimension.[54]

What is perhaps most important to remember is that errors for measurements made from one tracing aren't independent, because landmark points are used numerous times in cephalometric analsysis.[54] The larger the error of measurement, the greater the correlation between measures will appear to be, and this enhanced correlation will not be detected by standard statistical tests.[54]

Use of duplicate tracings to best establish point location helps decrease these types of error, although they will still be present in some degree. Additionally, Baumrind and Frantz[54] recommend discontinuing use of landmarks or measures which cannot be well enough defined to make them reliably reproducible.

FINDINGS

The means, ranges, and standard deviations were computed for the entire sample for the following angular and linear measurements at timepoints one, two, and three: articulare-pogonion length measured in mm, lower incisor angulation relative to the occlusal plane of the reference film measured in degrees, and distance from the lower incisor edge to the origin of the lower occlusal frame of reference (mesial cusp tip of the lower molar in the occlusal plane of the reference film) measured in mm and expressed in terms of the x,y coordinates of the lower incisor edge. The findings are summarized in Table II.

The same calculations were made for the changes in these parameters between timepoints one and two and timepoints one and three. These findings are summarized in Table III and the means are compared by use of Z-tests with an established alpha level of .05.

Examination of Table II shows a mean increase in articulare-pogonion length of 3.47 mm and 5.89 mm between the first and second and first and third timepoints respectively. These increases were determined to be statistically significant at the accepted level and show mandibular growth during these time intervals.

The lower incisor's angular relationship to the reference film's occlusal plane showed a slight mean proclination in the first time interval of -1.69 degrees and an uprighting of 0.09 degrees in the last time period. Neither of these changes were determined to be statistically significant.

The lower incisor edge position showed a mean retraction of 0.86 mm along the x axis in the first time interval and 0.96 mm in the second interval, both of which were statistically significant changes. The vertical position of the lower incisor edge showed a mean intrusion of 0.12 mm in the first interval, which was not a significant change, and a mean extrusion or eruption of 0.82 mm in the second interval which was significant.

No correlations of angular position of the lower incisor to mandibular length increase were attempted.

DISCUSSION

Problems are immediately encountered in any radiographic attempt to assess tooth position due to projectional errors, errors in identification of landmarks, and errors in construction of lines and angles to be measured. Although use of the computer-aided cephalometric analysis decreases the source of some of these errors, the rest cannot be eliminated if conventional lateral cephalometric films are used. Loss of articulare-pogonion length in a few instances could be caused by projectional error secondary to patient positioning in the cephalostat and would not be eliminated or quantified by the techniques used in this study.

Two of the reference landmarks in this study, the lower incisor apex and the mesial molar cusp tip, are difficult to locate with certainty due to lack of contrast with superimposed structures. Use of duplicate landmark location in conjunction with the AVEPIC program allowed a degree of certainty in knowing that the points were consistently located twice for any given film, but did not insure that the point so designated was in fact the actual location of that landmark. Even in instances where there is adequate contrast to show root apices or cusp tips clearly, one cannot be certain that one is tracing the same side molar in each film or that the most prominent incisor is the central.

Disadvantages other than those pertaining to radiographic technique relate to the ways growth can change the mandible itself. Bjork's implant work has clearly shown that rotation occurs with mandibular growth, and that remodeling along the lower border can disguise this roation and its effect on tooth position and eruption. The availability of an implanted study population allowed for superimposition on the implants rather than on the mandibular border and inclusion of the effects of rotational change on tooth position. None of the studies of post treatment lower incisor change reported in the literature involve use of implant superimposition techniques.

After implant superimposition, the occlusal plane of the timepoint one film was designated as the lower occlusal frame of reference and transferred to subsequent films for comparison of lower incisor position. This reference plane was used to give a more biologically meaningful reference than that created by using a line based on the location of the mandibular implants, which were somewhat randomly placed. The net changes in tooth position shown at subsequent timepoints would be identical if compared to an implant reference line or an occlusal plane reference line.

Of the total number of patients implanted at Oregon Health Sciences University, an attempt was made to select a sample consisting of 30 Class I male patients. Class I malocclusions were chosen because it was felt that these individuals would be most apt to show normal mandibular growth patterns, that is to say, severe mandibular prognathism or retrognathia would not be found or play a role in the development of the mandibular dentition. A sample of males would have been preferable, since males are well known to show longer and greater mandibular growth, and if late mandibular growth did result in retroclination of the lower incisor, it might be more apparent in a male sample. This was not possible, as most of the patients implanted in Oregon were females or Class II malocclusions, making selection of a mixed sex, Class I sample necessary. This sample did demonstrate continued mandibular growth, but probably not to the degree that would have been seen in an all male sample.

Another issue of major importance is the fact that the entire sample had been orthodontically treated, with lower arch extractions for the most part. The mean changes indicate retraction of the lower incisor of about one mm while maintaining the angular relationship to the occlusal plane through the study period. Eruption of almost one mm was seen in the last time interval. These results indicate that the lower incisor was bodily retracted and that this movement pattern was maintained beyond treatment and into the retention period. Late vertical changes may reflect relapse toward a more pronounced curve of spee. Treatment mechanics and retention have the obvious potential of altering normal maturational patterns.

The mean lower incisor/occlusal plane angle was about 63 degrees at timepoints one and three, and about 61 at timepoint two. The Down's analysis shows a mean of 76 degrees for this angle with a range of 70 to 87 degrees. The malocclusions in this sample presented with, and maintained, a more procumbent lower incisor during treatment and retention. Stability in lower incisor position in treatment is desirable in that the tooth in malocclusion is in a stable, functionally determined location. It would appear that the average treatment result did not produce a change in inclination secondary to Class II elastic use or "dumping" of the incisors with reverse curve in the arch wire. This maintenance of the lower incisor angle may indicate an interference with normal maturational change, however.

These findings contrast with Bjork's[23] long term follow-up of an untreated, implanted sample, in which he found proclination of the incisors. They are also in disagreement with the findings of Lundstrom[26] and Shudy,[44] who found retroclination of the lower incisor with mandibular growth in an untreated and a post-treatment sample respectively. Other studies previously cited fail to establish any consistent trends with respect to the lower incisor's angular position in the post-treatment and post-retention period. The large ranges reported in incisor position tend to support Brodie's[24] findings of great variation in lower incisor position amoung individuals, in spite of late facial growth and a generally decreasing prominence of the denture.

No evaluation was made of the casts for the sample population at any timepoint and, subsequently, no information was available with regard to the degree of mandibular crowding present initially or the degree of relapse that may have occured. An attempt to select cases with demonstrable relapse may have produced a sample with more pronounced lower incisor position changes.

Additionally, no attempt was made to specify a minimum time free of retention devices, which could well have altered the degree of change in incisor position seen radiographically. No attempts were made to determine if individuals had exhausted all growth capacity, but it is likely, since most were female and the average age at last evaluation was over 18.

Lastly, the most pronounced tooth movement change seen in the lower arch was the mesial migration of the lower molar, which was significant between the first and second and first and third timepoints, with means of

2.91 mm and 4.25 respectively relative to the origin of the occlusal frame of reference. The lower molar also showed significant vertical eruption with means of 1.59 mm and 1.90 mm for the same time intervals.

SUMMARY AND CONCLUSIONS

This study was undertaken to determine effects of post-treatment mandibular growth on lower incisor location and inclination in an implanted, orthodontically treated sample, evaluated at the end of treatment and after retention. Mandibular length increases were assessed by measuring the change in articulare-pogonion length, and lower incisor position was evaluated relative to the occlusal plane of each individual's pretreatment film after superimposition on mandibular implants.

Data was collected using a computer-aided cephalometric program developed by Baumrind in which all landmarks or reference points were recorded by direct digitization from the film or its acetate tracing. Each film was "traced" twice to ensure accurate point location within the computer's specified error range. All angular and linear measurements were done algebraically by the program, as were comparisons between time intervals.

Lower incisors were found to be minimally displaced in angular terms, although retraction measurable at the lower incisor edge was evident at all time intervals, as was eruption of the lower incisor in the last time interval. Uprighting changes such as those described by Lundstrom[26] and Schudy[44] were not found, nor was any increase in proclination as described by Bjork.[33]

Mandibular length increase was clearly evident, as was mesial migration and eruption of the lower molar.

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FIGURE I

MANDIBULAR IMPLANT LOCATIONS

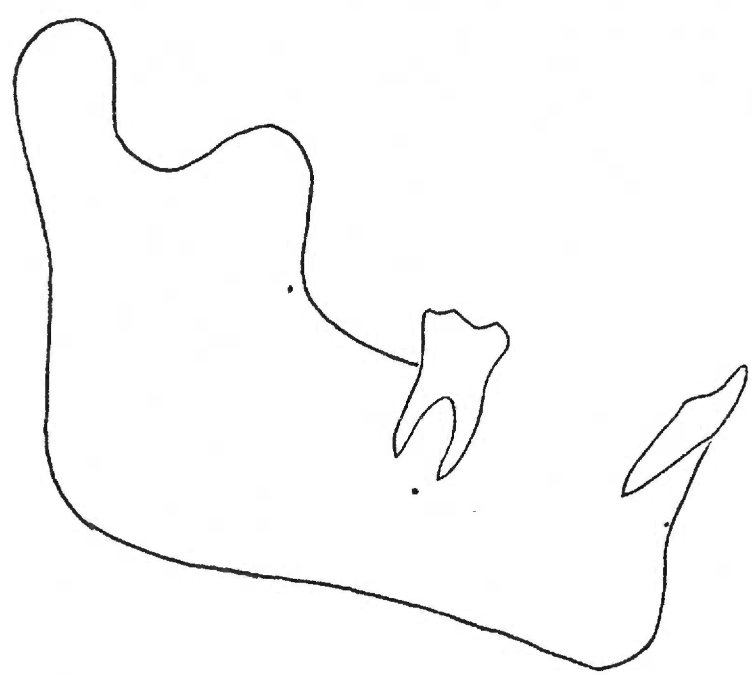

FIGURE II

TEMPLATE AND POINT LOCATIONS

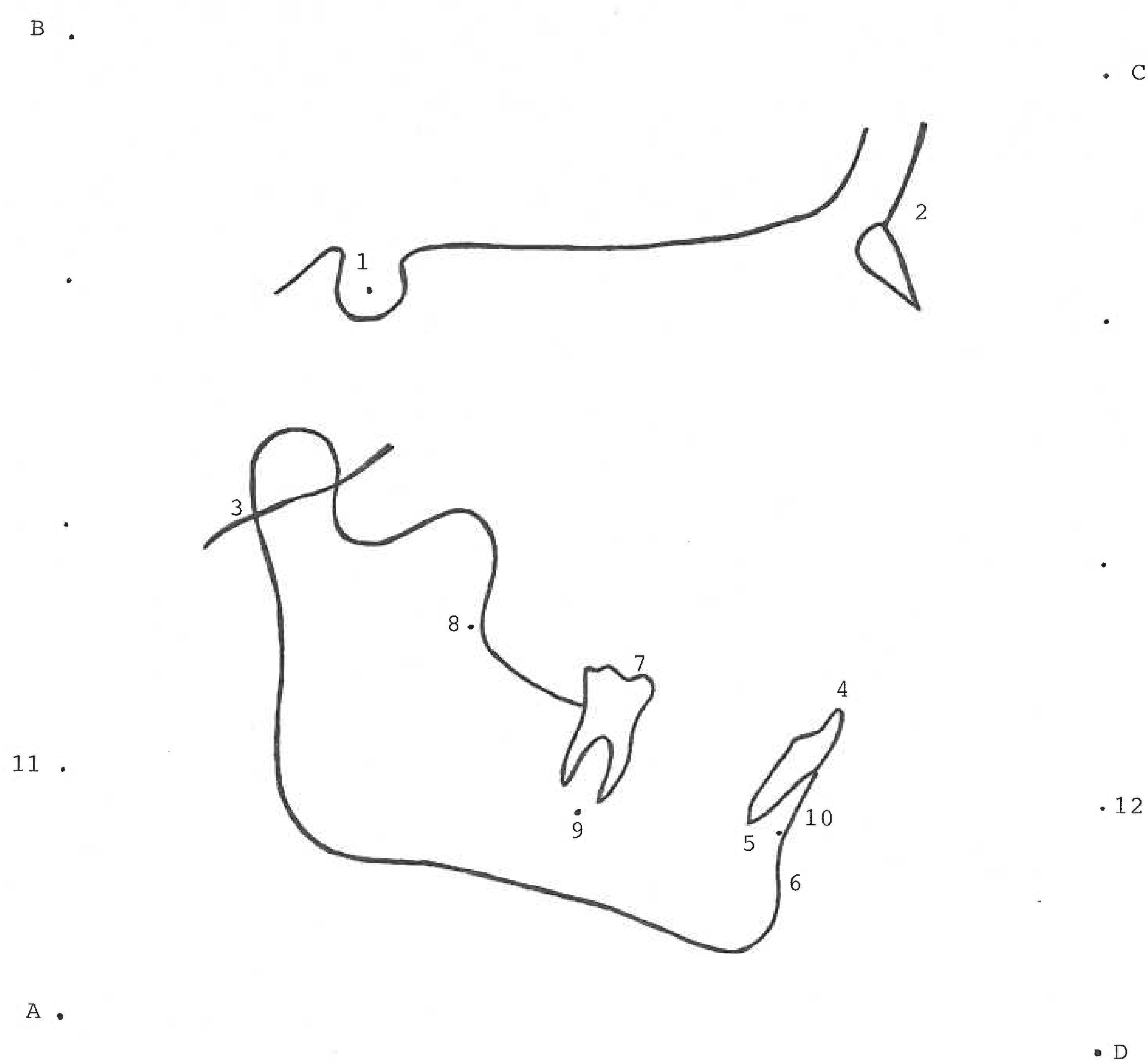

TABLE I

AGE PROFILE FOR STUDY POPLUATION
(decimal years)

	MEAN AGE	RANGE	STANDARD DEVIATION
T1	12.99	10.55 - 16.74	1.70
T2	15.36	12.95 - 19.08	1.61
T2	18.87	14.92 - 23.03	2.21

TABLE II

ANGULAR AND LINEAR MEASUREMENTS AT TIMEPOINTS ONE, TWO AND THREE

	T1			T2			T3		
	MEAN	RANGE	STD DEV	MEAN	RANGE	STD DEV	MEAN	RANGE	STD DEV
Articulare-Pogonion Length (mm)	104.09	93.14 - 111.16	4.76	107.56	97.96 - 115.43	4.54	109.98	99.84 - 122.65	5.25
Lower Insicor/ Lower Occlusal Plane (degrees)	63.08	51.20 - 73.72	5.50	61.39	45.42 - 76.28	7.04	63.18	48.25 - 79.87	6.35
Lower Incisor Edge - Origin of Lower Occlusal Plane (expressed in mm for x,y coordinate)	x 26.46 y 0	x 17.80 - 32.92 y 0 - 0	x 2.78 y 0	x 25.60 y -0.12	x 20.35 - 30.48 y -4.01 - 3.43	x 2.42 y 1.65	x 25.51 y 0.82	x 19.21 - 30.71 y -1.76 - 4.27	x 2.66 y 1.48

TABLE III

CHANGES IN ANGULAR AND LINEAR MEASUREMENTS

	T1-2			T1-3		
	MEAN	RANGE	STD DEV	MEAN	RANGE	STD DEV
Articulare-Pogonion Length (mm)	3.47	-1.86 - 10.49	2.83	5.89	0.0 - 14.52	4.21
	$z = 6.80$		$p \leq .05$	$z = 7.75$		$p \leq .05$
Lower Incisor/ Lower Occlusal Plane (degrees)	-1.69	-11.99 - 13.19	5.66	0.09	-11.03 - 6.18	4.02
	$z = -1.64$		$p > .05$	$z = .13$		$p > .05$
Lower Incisor Edge - Origin of Lower Occlusal Plane (expressed in mm for x,y coordinate)	x -0.86	x -3.73 - 4.63	x 1.84	x -0.96	x -3.18 - 4.38	y 1.78
	y -0.12	y -4.01 - 3.43	y 1.65	y 0.82	y -1.76 - 4.27	y 1.48
	$z(x) =$	-2.61	$p \leq .05$	$z(x) =$	-3.0	$p \leq .05$
	$z(y) =$	-0.4	$p > .05$	$z(y) =$	11.71	$p \leq .05$