Three Plane Analysis of Tooth Movement, Growth, and Angular Changes with Cervical Traction

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Introduction

Since 1938 when the orthodontic staff of the University of Illinois published its cephalometric appraisal of orthodontic results,[2] the x-ray of the head has come into increasing use as an auxiliary aid for the orthodontist. In addition to its employment as a means of comparing cases before and after treatment it has been used in the development of various analyses and for diagnostic and prognostic procedures. The preponderance of these efforts has resulted in qualitative findings and these primarily in a single plane.

Workers in the field of growth, conscious of its three-dimensional implications, have been discouraged by the multiple difficulties encountered in the management of the posteroanterior x-ray of the head. The lateral film images can be corrected to a single target-object distance with only a small margin of error. This makes the comparison between films a simple matter of superimposing tracings. The frontal film, on the other hand, offers a multitude of target-object distances, each of which must be corrected to derive accurate dimensions.

Publications by Kloehn in 1953 and 1961[7,8] called attention to some surprising changes that occurred in the form of the dental arches which accompanied the successful treatment of Class II malocclusions by means of extraoral forces exerted on only the maxillary first permanent molars. Since no orthodontic forces were applied to any other teeth, it seemed apparent that the favorable changes in the arches, anterior to the molars, must be due to natural causes, e.g., growth and/or musculature. These findings emphasized the importance of devising means to measure dimensions in the horizontal plane. A number of workers contributed to the solution of the problem.

Wylie and Elsasser[17] devised a compensator that permitted the derivation of absolute values from the enlarged dimensions of the head x-ray. Vogel[16] modified the compensator to eliminate the shifting of film and tracing between the frontal and lateral views and showed how to correct for asymmetries. Broadbent introduced an orientator which greatly simplified the positioning of the complementary films for tracing and projection. Downs[5] demonstrated the use of x-rays of models for delineation of dental arches and apical bases. Richardson and Brodie[14] showed how this technique could be modified to measure the dimensions and area of the apical base using a planimeter and the Stanton surveying instrument.

Advantage of these techniques was taken by Brodie[3] to make a longitudinal study of growth changes in the maxillary apical base; in 1966 the same author advanced evidence that the crowns

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of the teeth were under the control of the intestinal system, their root ends under control of the skeleton.[4]

Lude[11] employed the frontal film and model with the Wylie-Elsasser compensator to determine the mediolateral location of the root ends of the lower teeth, and the lateral head film and Vogel-modified compensator to establish their anteroposterior location. The plotting of the resulting points resulted in the accurate delineation of the form and size of the mandibular apical base as determined by craniometric measurements on dried skulls. Using Lude's technique, Lagios[10] studied the growth changes in the mandibular apical base in a series of growing children.

Lagerstrom[9] demonstrated that by the application of the Pythagorian proposition to coordinate systems at right angles to each other it was possible to relate the occlusal view of the model, representing the actual dimensions of the dental arch, with the enlarged dimensions of the lateral head film.

Material

This investigation was based on two groups of serial frontal (posteroanterior) and lateral cephalometric roentgenograms and occlusal roentgenograms derived from plaster models. The first group was composed of fifteen males and fifteen females, none of whom received orthodontic treatment. This was used as a control. The second group was composed of twelve females and four males, all of whom presented Class II malocclusion. All were treated by cervical traction only, to a Class I relationship. This was the experimental group.

Each series of the control group consisted of two sets of cephalometric roentgenograms of the head and x-rays of plaster models of the dental arches. The first series was taken at the age of 8 ± 1 year except for four cases, and the second series at 16 ± 1 year except for the same four cases. Two of the excepted cases were represented at 6 years for the first period and 14 years for the second period; the other two cases at 3 years for the first and at 11 years for the second period. The mean of the initial age period, called Stage I, was 8.44 years, and of the second age period, Stage II, 15.86 years. All of the control group exhibited excellent occlusions or mild Class I malocclusions.

Each series of the experimental sample consisted of three sets of roentgenograms of the head together with an x-ray of the plaster cast of the maxillary arch made at the same time. The mean of the initial age period representing beginning orthodontic treatment (Stage A), was 8.87 years, that at the time of retention (Stage B) was 12.84 years and that at the time of final record (Stage C) was 17.20 years.

The average treatment period was 2.3 years and Kloehn-type cervical traction was used on all cases. Twelve of the sixteen cases presented Class II, Division 1 and four cases Class II, Division 2 malocclusions.

All materials were obtained from the files of the Orthodontic Department, University of Illinois.

Method

The x-ray image of the model of the dental arch was obtained by placing the model, teeth down, on a film and directing the x-ray beam at the center of the base of the model from a distance of five feet. This yields an image of the dental arch without measurable enlargement and with satisfactory detail of the outlines of the individual teeth. Two small metal discs, previously fastened some distance apart on the palatal raphe of the model, permitted the construction of the midline.

All structures significant to this study, i.e., bilateral as well as midsagittal, which were revealed by both lateral and frontal cephalometric head films and from the x-ray films derived from the plaster models of the maxillary dental arch were traced with hard pencil on matte acetate. On the lateral film, all angular measurements were read to the nearest 0.5 degree, and all linear measurements were read to the nearest 0.5 mm by standard protractor and scale, respectively.

The following linear measurements were obtained (Fig. 1):

SPtm(L)—Center of sella turcica to the most inferior point of the pterygomaxillary fissure of the left side.

SPtm(R)—As above of right side.

Ptm6(L)—Pterygomaxillary fissure to the most posterior point on the crown of upper first permanent molar of left side.

Ptm6(R)—As above of right side.

PtmA—Pterygomaxillary fissure to point A read on the midline, tentatively accepted as representing the depth of the maxillary apical base.

Arch depth—The most posterior point of the crown of upper first molar to the most anterior point of the crown of upper central incisor read on the midline, representing dental arch depth.

Arch width—The most prominent buccal points on the crowns of upper first molars between left and right sides representing dental arch width.

The following angular measurements were obtained (Fig. 2):

BaSN—

SN/FH—Relation of Frankfort horizontal plane to anterior cranial base line.

Pal/FH—Relation of the palatal plane to Frankfort, tipping up designated +, tipping down —.

Occ/FH—Relation of the occlusal plane to Frankfort, closing angle designated —, opening angle +.

NSGN—

NS6—Relation of 6's (midpoint between buccal groove of right and left upper first molars) to anterior cranial base line.

Pal6(L)—Inclination of axis of upper left first molar to palatal plane. Mesial crown tipping was read as —, distal tipping +.

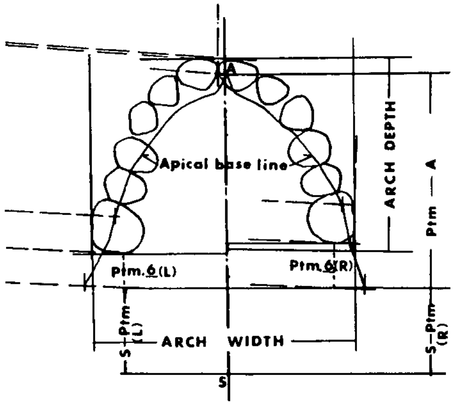

Fig. 1 Measurements in horizontal plane derived from x-ray of model positioned by compensated projections from complementary frontal and lateral cephalometric x-ray films. Apical base outline drawn by connecting points indicating root apices.

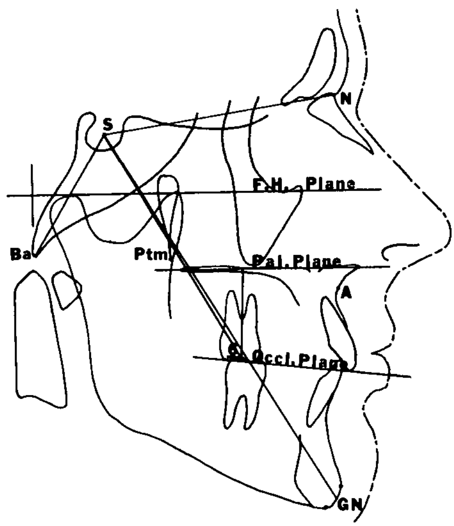

Fig. 2 Points, planes and angles derived from lateral cephalometric x-ray film.

Pal6(R)—As above of right side.

Symmetry was determined by almost perfect superposition of left and right structures on the lateral film; Lagerstrom's technique[9] was followed in all such cases (Fig. 3).

Basic to the three-plane projection of *asymmetrical* cases is the necessity of accurate positioning of the frontal and

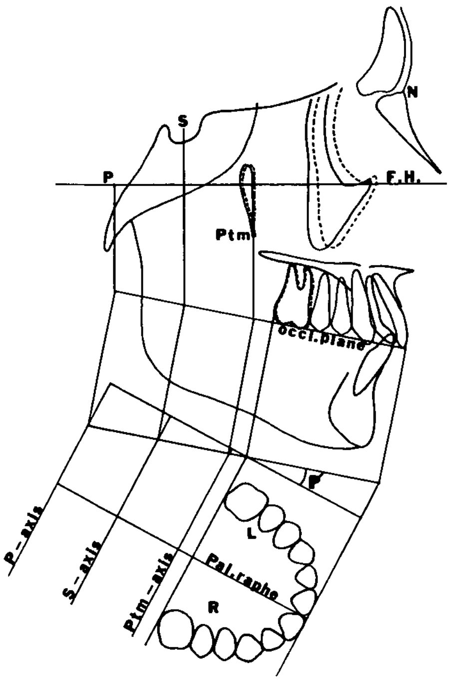

Fig. 3 Registration of coordinate systems and construction of correctional angle (P¹) according to Lagerstrom.

lateral films for tracing so that accurate projections can be made from one to the other. This requirement was met by the Broadbent-Bolton orientator, the use of which has been described by Lude[11] (Fig. 4).

On the tracing of the posteroanterior film, the horizontal porionic axis was drawn along the superior surfaces of the right and left earposts' shadows. A perpendicular to the porionic axis was drawn through crista galli, nasal spine and continued downward through the incisors. In the completely symmetrical and properly positioned head, it will pass through the tip of the odontoid process of the axis and between the central incisors. This perpendicular should also bisect the distance between the ends of the earposts, indicating the midsagittal plane of the head-holding device. Lack of the coincidence of the line with one passing through the point of bisection may indicate difference in the width of the two sides of the head or earposts placed at unequal depth in the canals. Finally, if the midline does not pass between the central incisors, a perpendicular which does so must be drawn in order to provide one of the three points necessary to position the tracing of the occlusal film of the dental arch accurately.

According to Wylie's method, if the case represented neither asymmetry nor incorrect positioning in the headholder, the anteroposterior position of any desired structure could be determined on the drawing from the dimension on the lateral film tracing, measured by a cor-

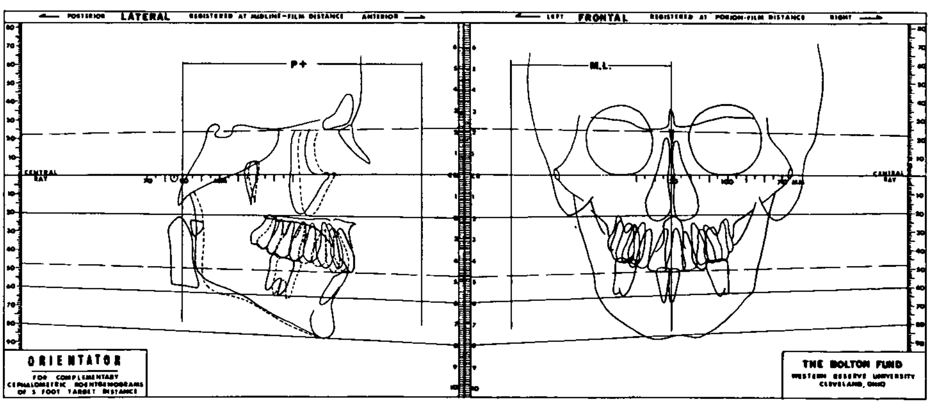

Fig. 4 The orientator with tracings of lateral and posteroanterior head films correctly positioned. (Courtesy of Dr. B. Holly Broadbent)

rectional scale or by the formulae of proportion.

In cases that present asymmetry of structure or incorrect positioning of the head, it is not possible to use the lateral head film to obtain the correct measurement of anteroposterior positions with the correctional scale or formulae of proportion. The correctional scale or formulae reveals the exact proportion of enlargement at only a five-foot distance, i.e., at the midline of the headholder. In order to determine the accurate anteroposterior positions of structures lying closer to or farther from the midline, e.g., right and left molars, Vogel's technique was employed in this study.

This technique is based on Wylie's compensating method, as refined by Vogel. Since the images of lateral and frontal films were taken with the head in the same position in the machine, a method was employed to project points on teeth which were clearly discernible on both the lateral and frontal films to the third (horizontal) plane of space.

The left side of Wylie's compensating bedplate was altered by Vogel who cut it in an arc concentric to one of a five foot radius so that the compensating idea which was employed for the frontal head film could be adapted to the lateral head film (Fig. 5).

The common plane of reference to both the frontal and lateral views is the horizontal plane, which corresponds to the porionic axis of the frontal head film and to the horizontal plane of the lateral head film. Since Frankfort horizontal does not necessarily coincide with the horizontal plane of the machine on the lateral head film if the head was not correctly placed in the headholder, it is not possible to use Frankfort horizontal plane as the common third plane to the frontal. Therefore, as described for the placement of both frontal and lateral head films on the Broadbent-Bolton orientator, the common plane of the lateral head film to the transporionic axis of the frontal is the central ray line. Since the porionic points determine the common third plane to both frontal and lateral views, the line is extended to both right and left sides (Fig. 5). A line is drawn parallel to the porionic axis and above it at the frontal film-porion distance (P+). This is the frontal film line.

Perpendiculars are drawn from the frontal film line tangent to the buccal surfaces of the upper right and left molars and to the contact point between the upper central incisors. From their points of intersection with the frontal film plane, lines are drawn using Wylie's compensator and its associated T-square. These lines represent the course of an x-ray beam from a source five feet away and mark the corrected lateral boundaries of the dental arch at the first molars.

To the left and right of the midline, perpendiculars to the porionic axis are drawn at the lateral film-surface distance (M.L.), which is also obtained from the data registered on the film at the time of exposure. That on the left represents the lateral film surface and the vertical porionic plane for the left side, that on the right represents the vertical porionic plane for only the right side.

The lateral film presents the superimposed images of the right and left sides. These must be traced separately, the right side directly on the master tracing to the right of the frontal tracing registered on the horizontal and the porionic planes. The tracing of the left side must be made separately and placed *face down* to the left of the frontal tracing and similarly registered on the horizontal and film surface line. Now all determinations have been related to three rectilinear coordinate systems at right angles to each other.

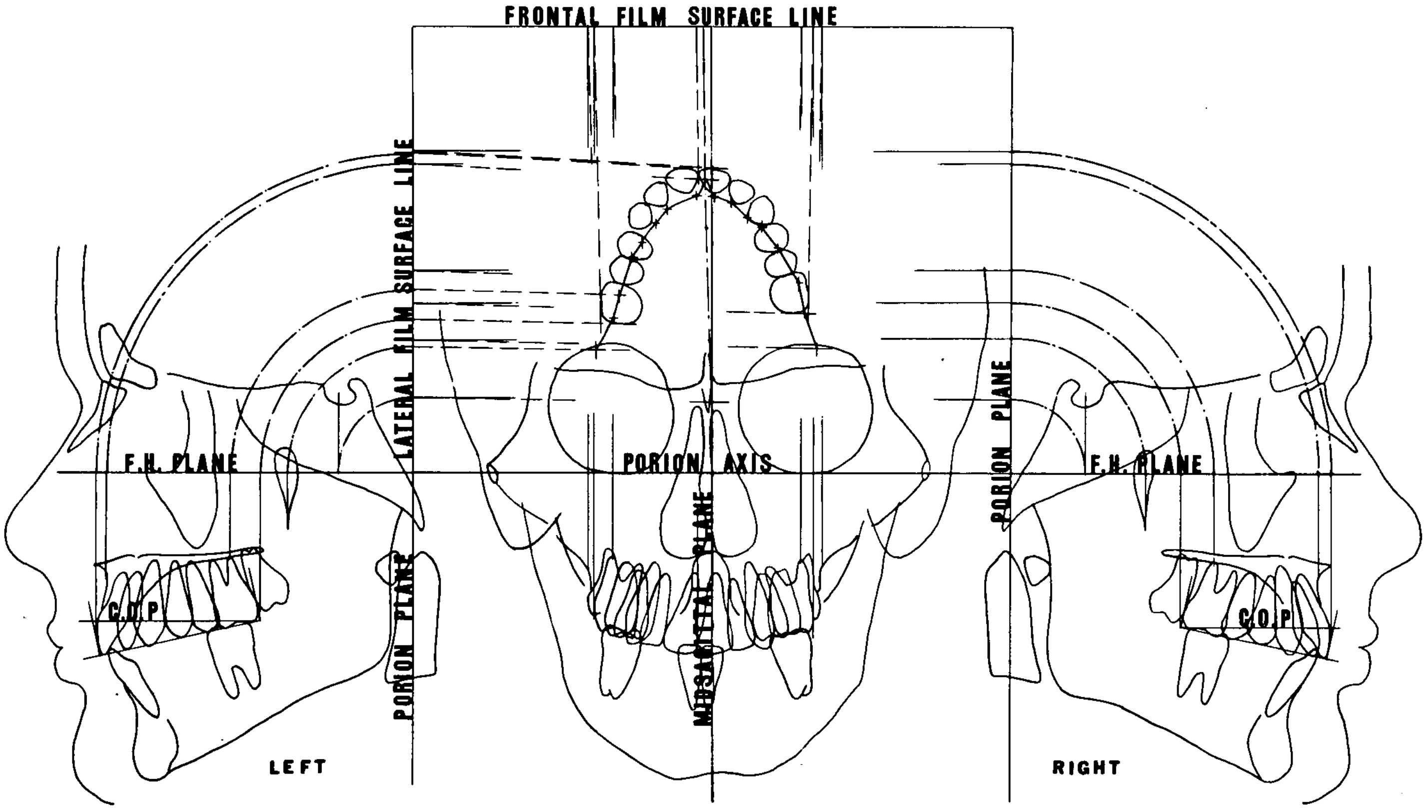

Fig. 5 Master tracing showing method used to coordinate enlarged measurements derived from frontal and lateral cephalometric x-ray films with absolute values derived from model.

In the management of the occlusal plane as viewed from the lateral aspect, allowance must be made for the fact that it is neither perpendicular nor parallel to any of the three coordinate systems. Coordination is accomplished as follows:

On both the right and left lateral tracings, two perpendiculars to the occlusal plane were drawn tangent to the most distal point of the upper first molar and to the most labial incisal point. A correctional occlusal plane [C.O.P.] was drawn parallel to the horizontal plane passing through the point of intersection of the perpendicular from the molar to the occlusal plane line. An arc was scribed from the incisal point to the corrected occlusal plane with its center at the point of intersection. Perpendiculars were drawn from the molar and incisal points on the corrected occlusal plane line to the porionic axis and arcs were scribed from these points to the vertical porionic line, respectively, with the centers at the intersections of the horizontal and porionic planes.

This served to transfer points derived from the lateral views to their anteroposterior positions in the horizontal plane. Since both right and left structures are shown on the same lateral-film surface, they must be projected separately to that surface, those of the left side directly by drawing the arcs mentioned above. Points on the right side must be projected across to the film surface line on the left side.

In asymmetrical arches this will result in two points on the lateral-film surface line for each bilateral structure. Both must be corrected for enlargement due to ray divergence. Correction was made by means of the Vogel modification of the Wylie compensator, the left side of which is cut to an arc with a five foot radius. Using the modified T-square, lines were drawn passing through the points and extended to intersect the corresponding projection from the frontal-film surface line. These served to position the occlusal film tracing anteroposteriorly and mediolaterally by registering the occlusal tracing on the incisal midline and bringing the right and left first molars' outlines into their tangential relations with the projections from the frontal and lateral-film surface lines. The tracing of the dental arch as well as the outline of the apical base could now be transferred to the master tracing.

In this study the determination of the apical base was made according to the technique of Lude, i.e., from the apices of the teeth. Each of these was located on both frontal and lateral tracings and projected to the occlusal tracing as described above. The points were connected from the distobuccal root of the first molar of one side to that of the other. The area was closed in back by a straight line connecting the two molar points. This area was called the Anterior Apical Base and was measured by polar planimeter and expressed in square millimeters. The area closed posteriorly by a straight line connecting the right and left Ptm was called the Total Apical Base and measured in the same manner.

The final step in the preparation of the master drawing consisted of the location of points from which craniodental relations could be determined by precise measurement. A glance at Figure 5 will show that this is accomplished in the same way that the molar and incisal points were, i.e., by arcs drawn from the horizontal to the lateral-film surface line where they are similarly corrected for ray divergence with the compensator. The projection from the center of sella turcica was carried to its intersection with the midline and those from the right and left pterygomaxillary fissures to locations in back of the dental

TABLE I

Measurement	Stage I		Stage II	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.
SPtm(L)	17.6	2.04	19.3	2.68
SPtm(R)	18.0	1.96	19.9	2.43
Ptm6(L)	6.0	1.80	12.8	2.88
Ptm6(R)	5.9	1.70	12.6	2.79
PtmA	42.5	1.79	47.3	2.25
Depth	39.9	1.34	39.1	1.93
Width	52.9	4.08	54.8	4.01
BaSN	129.4	4.39	129.3	5.05
SN/FH	7.0	2.81	7.3	2.94
Pal/FH	—0.7	3.03	—1.1	3.86
Occ/FH	12.6	3.73	9.9	4.02
NSGn	65.5	3.34	64.9	3.30
NS6	66.0	3.58	65.6	3.20
Pal6(L)	16.1	6.65	8.5	5.20
Pal6(R)	15.2	6.16	7.4	5.28

arch on its corresponding sides. Given tracings of the cephalometric x-rays and of plaster models taken in time series it is now possible with standard scales to measure the difference between them due to growth and/or orthodontic procedures.

FINDINGS

The purpose of this study was to reveal effects induced in orthodontic treatment by means of cervical traction as such effects might be influenced by normal growth. Many investigations have been conducted on the position of the upper first molar but it should be kept in mind that any changes, even of small degree, must take growth influences into account.

In Table I are the means and standard deviations for the linear and angular measurements from the control group. The differences between the two stages of eight and sixteen years are apparent. Table II shows the figures for the three stages of the experimental group and again the differences are evident.

The differences between Stage A and Stage B would reveal the effect of the treatment of the cervical traction compared with the untreated normal growth behavior as to the location and extent of changes. The differences between Stage B and Stage C would reveal what happened to these changes after retention, and the differences between Stage A and Stage C would show how the total changes compared with those of the untreated controls.

Linear and angular differences

SPtm measured between perpendiculars to Frankfort showed the same stability of the mean as that of numerous other studies. There were small increases in the control group. The treated group revealed a slight tendency

TABLE II

Measurement	Stage A		Stage B		Stage C	
	$\bar{X}$	S.D.	$\bar{X}$	S.D	$\bar{X}$	S.D.
SPtm(L)	18.8	2.55	17.7	2.48	18.8	2.80
SPtm(R)	18.3	2.90	18.0	2.63	18.6	2.78
Ptm6(L)	7.6	2.82	7.9	2.34	10.6	2.74
Ptm6(R)	8.2	2.88	8.0	2.15	10.8	2.49
PtmA	45.3	2.41	46.3	2.09	46.8	2.44
Depth	43.0	2.26	42.1	1.74	40.5	1.95
Width	54.7	2.76	57.5	2.74	57.6	2.29
BaSN	129.3	5.25	128.8	4.95	127.9	5.64
SN/FH	8.0	2.64	7.8	3.20	7.6	3.02
Pal/FH	0.3	3.75	—1.4	3.72	—1.3	4.20
Occ/FH	10.8	4.43	10.9	3.42	9.8	3.92
NSGn	67.0	2.95	68.1	3.10	67.8	3.52
NS6	67.7	2.47	69.6	2.60	68.1	2.76
Pal6(L)	16.5	4.53	12.3	5.19	7.9	6.22
Pal6(R)	15.5	5.06	11.0	4.38	7.3	5.62

to decrease during treatment but subsequently regained most of it.

Ptm6 exhibited great stability during treatment in contrast to the significant increase shown by the control. Its normal rate of forward movement was resumed following treatment.

PtmA showed significant increases in the control but they were somewhat smaller than those of Ptm6. In the experimental group the increase was considerably less and when the SPtm and PtmA measurements were combined case by case, decreases as well as increases were found. The difference in behavior between the two samples in what might be regarded as the depth of the maxilla at point A has been noted before.[3] Increases in width in the canine area at puberty have been demonstrated in both normal and Class II cases but those accompanying the successful reduction of Class II to Class I occlusions are significantly greater. Such anterior widening is accompanied by a flattening of the anterior arc of the maxilla which results in a loss of the depth that would otherwise be attained.

Dental arch depth and width behaved in a similar manner. During treatment, depth decreased slightly while width increased significantly. Following treatment the decrease in depth continued but width remained the same.

The cranial base angle (BaSN) and the angle formed by the anterior cranial base and the Frankfort plane (NS/FH) revealed small changes of both increase and decrease that resulted in stability of their means.

The angle formed by the palatal plane with the Frankfort plane in the control showed a slight tendency to open, i.e., for the palatal plane to tip down in front. In the experimental group the angle tended to open during treatment and to partially close thereafter. The result was a net decrease of -1.6 ± 2.3 for the entire period of observation.

The angle formed by the occlusal plane with the Frankfort plane showed decreases in both samples but that in the controls was greater, seeming to indicate that treatment slowed but did not inhibit the normal tendency. The decrease was continued after treatment. Wide variation was shown among the subjects in their responses to treatment probably indicating large individual differences in growth rates.

The angles NSGN and NS6 were shown to open in the treated group and to close in the controls. Other studies have demonstrated a pubertal advance of GN without change of the relation of 6 to the Y axis (SGN). Thus NS6 would be expected to show a closing tendency in untreated cases. On the contrary, any treatment involving the backward movement of the molars or even the inhibition of their normal forward and downward movement results in an opening of the NS6 angle. Such a change has been shown to be accompanied by a downward and backward rotation of GN which explains the opening of the NSGN angle. Following treatment this angle tended to return toward its original values or to remain stable. NS6 invariably showed decrease as it regained its former axial inclination.

The angle formed by the axis of 6 and the palatal plane was shown to close in both the control and the treated group but the decrease in the treated group was only slightly more than half of that of the control during treatment. Following treatment the decrease continued until it was slightly greater than the control over the entire period of observation.

Apical Base

The area of the apical base was measured by a planimeter at each stage of the control and experimental groups. Both

TABLE III

	Total Apical Base		Ant. Apical Base	
	Mean	S.D.	Mean	S.D.
Stage I	1579	159	901	125
Stage II	1962	214	986	118
Difference	383.5	193.0	84.1	98.7

the total apical base (Ptm to point A) and its anterior area (apices of the distobuccal root of the first molar to point A) were measured.

In Table III are the means and standard deviations of the total and anterior apical bases and also of their differences in the control sample. For the experimental group the same information is given in Table IV.

Since most of the growth of the maxilla takes place at the tuberosity area, it was necessary to obtain the total growth change of the apical base which would provide room for the permanent molars. The growth at the back of the maxilla carries that bone and the upper dental arch forward. This results in the dental arch being moved into an environment that is largely under muscular control. From this point of view it was considered necessary to determine the changes of the anterior apical base area which is closely related to the dental arch.

All individuals of the control group showed a definite increase of the total apical base (Fig. 6). The difference between Stage I and Stage II, i.e., the mean growth increment from eight to sixteen years, was 383.5±193.0 sq. mm. This is obviously dependent on the growth of the maxillary tuberosity area. The great increase between Ptm and the upper first molars, which was shown before, contributes this increment. In the area of the apical base anterior to the first molar, twenty-four cases (82.8%) showed increase and five cases (17.2%) decrease. The mean change was 84.1 ±98.7 sq. mm. It was also revealed from the superimposition of the different two

TABLE IV

	Total Apical Base		Ant. Apical Base	
	Mean	S.D.	Mean	S.D.
Stage A	1786	161	945	107
Stage B	1919	126	1071	110
Stage C	1973	145	1018	79
Diff. A B	133.7	113.2	125.6	71.9
Diff. B C	47.5	85.5	—53.1	77.7
Diff. A C	181.2	135.6	72.5	86.4

stages that much of the increase took place at the posterior region by an increase of its width.

All cases in the experimental sample showed an increase which yielded a mean of 133.7±113.2 sq. mm at the time of retention (Figs. 7, 8, 9). From the end of retention to time of final records a mean increase of 47.5±85.5 sq. mm was shown. Sixty-two and a half per cent increased and the rest decreased. Since the apical base was determined by the location of the apices of the teeth which may have been influenced by the orthodontic force, its shape or area would possibly not repre-

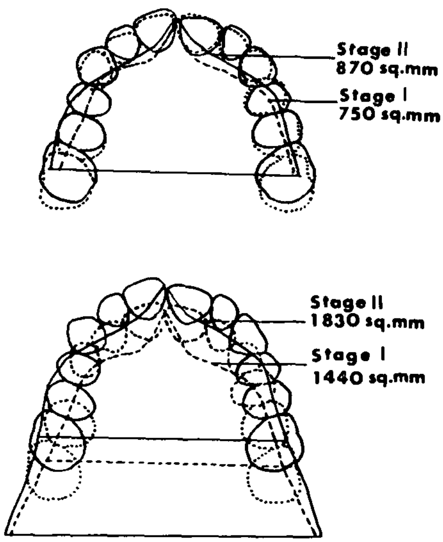

Fig. 6 Above—Typical anterior apical base change of the control group. Below—Typical total apical base change of the control group.

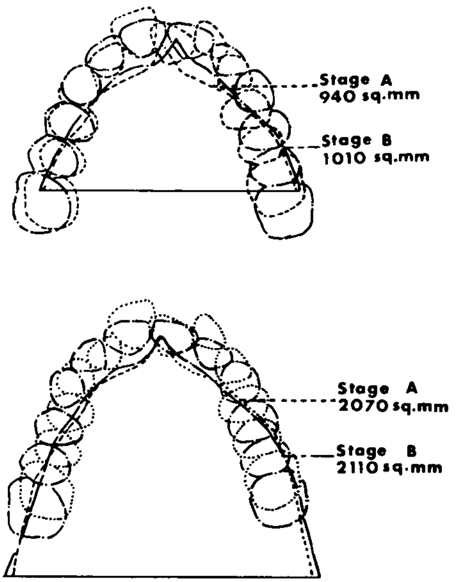

Fig. 7 Above—Anterior apical base change of the experimental group between Stage A and Stage B. Below—Total apical base change of the experimental group between Stage A and Stage B.

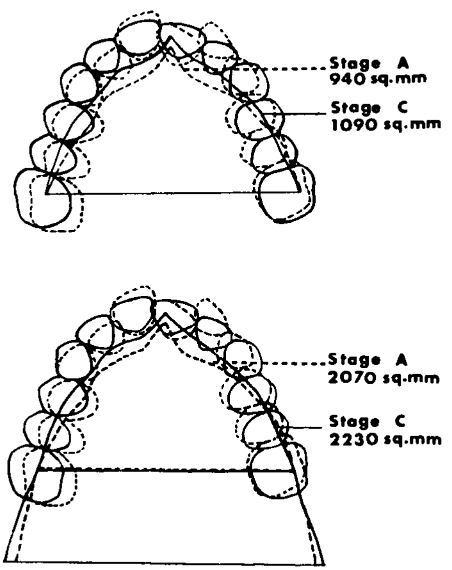

Fig. 8 Above—Anterior apical base change between Stage B and Stage C. Below—Total apical base change between Stage B and Stage C.

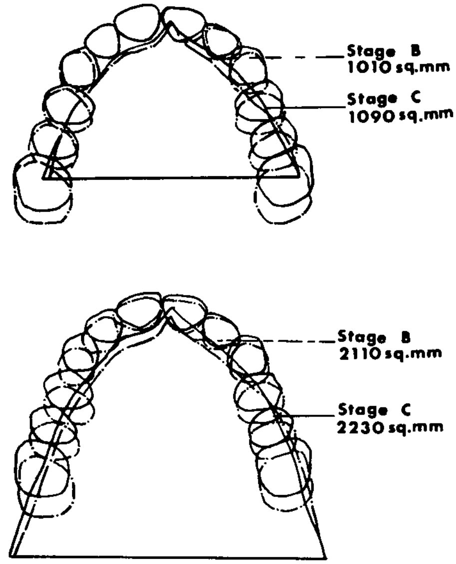

Fig. 9 Above — Anterior apical base change between Stage A and Stage C. Below—Total apical base change between Stage A and Stage C.

sent the conditions solely of a physiological environment. Therefore, the increase at the time of retention or the decrease at the time of the final record might be subjected to misinterpretation if it were taken as the true apical base under physiological conditions. In order to obtain the true change of the apical base completely relieved from orthodontic manipulation, the difference between Stage A and Stage C, i.e., between pretreatment and the final record, was taken.

The change of the total apical base between Stage A and Stage C showed a mean increase of 181.2±135.6 sq. mm. This increase was surprisingly small compared with the increase in the control group (383.5), and seemed obviously attributable to the cervical traction. The change of the anterior apical base showed a mean increase of 72.5± 86.4 sq. mm. This was almost the same as the change in the control group (84.1±98.7).

The increment of the apical base

growth was mainly due to the growth of the maxillary tuberosity, but small increases also occurred on the outer surface of the maxilla. This main growth site of the maxilla, the tuberosity, was found to be interfered with by the cervical traction, which means that its growth potentiality may be delayed and/or decreased.

The apical base showed a tendency to be flattened anteriorly during the growth period.

Discussion

Critical analysis of the data derived from this study indicates the necessity of more exact technique in the utilization of cephalometric roentgenograms. The almost universal procedure of comparing serial stages by superposing tracings of uncorrected lateral films reduces the findings to those of a qualitative nature and these in only two planes. Changes in size and form in the horizontal plane cannot be estimated, much less measured. These reduce findings to value judgments by the operator.

The human head is a three-dimensional object and no such irregularly-shaped object can be evaluated by viewing it from only one side. Viewing it from in front often results in an entirely different opinion of its characteristics. Yet this is the risk that is taken when clinical decisions are based only on profile findings.

It must be granted that an analysis involving three dimensions is much more involved and time-consuming than one requiring only the tracing of a few clearly-defined anatomical details. Of primary importance is the correct positioning of the head in the cephalometer and its maintenance while the frontal and lateral exposures are made. Only by such control is it possible to relate all discernible structures to the three planes of space and to measure their relations to each other in terms of their absolute values. These conditions can be met only with equipment that provides fixed relations between the headholder and two x-ray tubes, the central rays of which (1) lie in the same horizontal plane, (2) are at right angles to each other, and (3) are at the same known distance from their sources to their point of intersection at the center of the headholder. To allow for differences in the widths and depths of various heads there must be provision for deriving the absolute distances from the point of intersection to the respective film surfaces.

Few facilities in use today are designed to meet the requirements set forth above, but a realistic attitude would question whether advantage would be taken of them if they were available. It would not be reasonable to expect the busy clinician to devote the necessary time to derive absolute values of all tooth movements, but on the other hand it is misleading to publish such values as though they were absolute when they are derived from methods that are less than scientifically accurate. This tends only to perpetuate errors regarding the effectiveness of certain orthodontic procedures and to obscure the causes for the remarkable changes frequently seen in orthodontic cases.

Analysis of the data leads one to question the wisdom of relating tooth movements to cranial points of reference. True, such procedures reveal the gross movements of the teeth in space but they tend to slight or even obscure those occurring within the denture itself. This is unfortunate because these movements are the only ones that can be effected by the orthodontist and hence their true magnitude and direction should be known to him. For these reasons it is suggested that changes occurring in the denture be analyzed in relation to the occlusal plane and that such analysis include the third (horizontal) plane. Beginning with the occlusal x-ray of the plaster model, an object of known dimensions, it has been shown that it is possible to carry such dimensions into other planes at their true values through spatially-related coordinate systems. When this is done it becomes more readily possible to separate the changes due to orthodontic management and those which have occurred as the result of growth. The latter include those in the horizontal plane, i.e., depth and width, with the resulting changes that these introduce in form and area of the dental arch and the apical base.

Findings of the present study compare closely with those derived from other samples in those details relating to the cranial base. The angle BaSN was shown to vary randomly in both the control and experimental groups but such changes, when they occurred, were small. The mean value remained unchanged. SN-FH behaved in a similar manner, i.e., it showed a strong tendency to remain unchanged. This likewise has been shown in earlier studies.[1]

The anteroposterior distance from sella to Ptm, measured parallel to FH, showed both increases and decreases but both were of small degree over the eight year interval covered. This dimension marks the location of the hafting zone between cranial and facial skeletons; its stability during growth has been commented on in a number of works.

In the experimental groups SPtm showed a slight tendency to decrease during the period when the cervical traction was acting. This amounted to only a millimeter or two and was cancelled by an increase of equal size during the posttreatment period. It might be expected that the amount of change of Ptm would be influenced by the amount of force being exercised by the traction, by the sex and age of the subject, and the length of treatment. It would seem that the tendency to return to pretreatment values is the most significant indication of the long-range stability of this landmark.

All quantitative studies directed toward the determination of this site of bone growth by means of vital markers, e.g., madder, alizarin, lead acetate and tetracyclines, have indicated prolific growth at the posterior margin of the maxilla. This, coupled with the stability shown at Ptm, seems to explain the behavior of the Ptm$\underline{6}$ dimension in both the control and experimental samples. The first indicated increases of six to seven mm while the second revealed little or no change during the treatment period. Following the discontinuance of distal force against the first molars, the increase between Ptm and the molar was resumed and continued until this distance amounted to about half of that of the control.

The PtmA distance also revealed differences between the samples. The control showed increases of five to six mm which was almost the same as the increase at the level of the dental arch seeming to indicate forward positioning of the entire maxilla. The experimental sample revealed that the mean of this distance also increased over the entire span of management but to a smaller degree than in the control. However, the increase was greater during the treatment period than subsequently which is thought to be due to the rather marked changes in form of the apical base and dental arch that occur with this method of treatment. Superposing lateral tracings with sella registered revealed both increases and decreases at point A. This indicated that when the SPtm and PtmA are combined, as they are in superpositioning, the variations present in each of the two segments may be combined in such a manner as to increase or decrease the sella-A dimension.

Dental arch depth decreased in both the control and experimental samples although the difference between their means was small. Arch width on the other hand increased in both groups, the mean increment being 1.9 mm for the control and 2.8 mm for the treated group. The gain in width occurred during the treatment period and was maintained thereafter; arch depth continued to decrease after treatment.

The behavior of the palatal plane and the occlusal plane in the control sample was similar to that observed by Brodie in other samples, viz., stability of the palatal plane with only a very slight tendency toward a lowering anteriorly, while the occlusal plane showed a definite tendency to be lowered posteriorly, i.e., to become more horizontal.

The findings of the treated sample were somewhat different. The palatal plane exhibited a slight tendency to increase its angulation to the horizontal during treatment and to recover only partially thereafter. The occlusal plane showed considerable variation in its behavior during treatment, some cases increasing and some decreasing. The mean indicated that increases and decreases were nearly equal since it was only 0.1 but the variation was 3.4 degrees. After treatment it showed a definite tendency to decrease although the extent of recovery varied widely within the sample.

An examination of the growth behavior of the axial inclination of the first molar in the control sample revealed the typical eruption pattern of that tooth, i.e., a steady mesial rotation of the tooth from a position where its occlusal surface faced almost distally to one in which it faced occlusally. Read as an angle with the palatal plane, that on the right decreased 7.8 ± 4.7 degrees and that on the left, 7.6 ± 5.7 degrees over the eight to sixteen year age span.

Findings from the treated sample revealed changes similar in kind, i.e., decrease in the means (4.5 ± 5.6 and 4.2 ± 6.7). Readings made of the total changes from beginning to end of the observation period were even greater than those of the control group (8.2 ± 5.7 and 8.6 ± 5.9 degrees, respectively). The reason for the difference in behavior between the control and treated groups in this regard seems to be indicated by the data on the angles NS-$\underline{6}$ and NSGN. In the controls both exhibited great stability but during the period of active treatment both showed a tendency to increase. This would indicate that the molar was either being restrained or moved backward tending to rock the mandible down and backward. The great degrees of variation in both the angular and linear measurements reflect the differences in rates of growth encountered among the individuals in the sample. It has been shown by Epstein that the higher the rate of growth, the less the disturbance in the normal behavior of the palatal, occlusal, and mandibular planes, and axial inclination of the molars.

As Brodie[3] has pointed out, the crowns and the roots of the teeth are under the influence of different environments, that is, the crowns are under the influence of the digestive system (tongue, cheeks and lips) while their apices are under the influence of the skeletal system. Viewed in this manner, it would be expected that the apices of the roots would be affected by the skeletal growth pattern. In the present study, therefore, the apices of the roots were considered the points which delineate the apical base periphery; the area enclosed by such a perimeter was considered to be the apical base.

The treated sample showed a mean change in the total apical base from Stage A to Stage C that was 202 sq.mm less than that of the control. The difference seems to indicate that cervical traction can delay and/or decrease the potentiality of maxillary growth. All of the cases showed an increase at the time of retention, but it is not possible to state with certainty that the apical base grew or did not grow during the treatment period. As mentioned before, the root apices during this period might be under the influence of the orthodontic force. This seems to be supported by the fact that the anterior part of the apical base during the treatment period showed almost the same increase as did the total apical base and most cases showed a slight decrease after the retention. This may indicate that, after the apical base was fully released from the orthodontic influence, it settled itself into its true physiological condition. The difference between Stage A and Stage C of the anterior apical base would be considered to be the natural change which did not include any orthodontic influence. Its mean and variability are almost the same as those of the control group. This fact may indicate that the apical base anterior to the first molars shows the area increase during the growth period and orthodontic treatment.

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