A COMPUTER AIDED STUDY OF THE VECTOR OF MAXILLARY CHANGE

IN 20 FEMALES UTILIZING THE IMPLANT METHOD

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TABLE OF CONTENTS

INTRODUCTION

The ancient Greeks exhibited an early interest in facial form which may have been primarily for artistic reasons.[1] Hippocrates (460-357 B.C.) was a pioneer in physical anthropology, making numerous descriptions as to the variety of skull forms but not employing measurements to distinguish the characteristics he noted.[2] Leonardo da Vinci (1452-1519) was one of the first persons to apply head measurements for assistance in studying the form of the human head.[2]

The first scientific study of craniometry was done by Spigel (1578-1625) who introduced the "liheae cephalometricae" to describe differences in form. Spigel and other early physical anthropologists were more concerned about describing racial characteristics and indices of proportions than studying growth.[1]

The study of growth was initiated by early scientists whose attention was focused on individual bones. Holes were drilled or wires were placed into the bones of living animals which were later sacrificed to determine the changes in the positions of the markers.[3] Hunter studied the growth of the mandible using madder as a vital stain.[1]

Knowledge is limited to the degree of development of the technics of study. In terms of human growth, development of the face had to be determined by comparing the skulls of young people. Such a sample would perhaps not be generated by normal children but rather individuals who did not survive due to some malformation.

Tandler, in 1912, suggested the use of x-rays in anthropometry as a noninvasive method to study the skull.[3] This allowed researchers to take into account many more features than the early craniologists had access to.

Hofrath in Düsseldorf and Broadbent in Cleveland independently developed radiographic technics for in vivo cranial study.[2] Broadbent's method predominated, using a cephalostat to give a reproducible head position with a standardized radiographic technic to produce an image. The comparison of such images allows for the determination of changes that may be the result of growth or orthodontic treatment.[4]

Broadbent's initial growth study described the growth of the average child and did not take into account normal variation but only extreme variation due to severe illness or abnormal growth patterns.[5]

Brodie produced the first serial growth study using cephalometric radiography, however, his composited drawings of the sample at each age erased any observations of individual growth variations. He concluded that growth is regular and once a morphologic pattern is attained, it does not change.

Merideth recognized the need for the study of individual variations in growth and growth changes.[6] While he revealed average changes, he also stressed the variations that exist in an individual's growth pattern shedding doubt on prediction.

Several workers[7,8,3,9] have recognized that remodelling of bones through apposition and resorption will change the external contours of bones that may falsely be attributed to growth. To detect the extent of the remodelling and to give a more accurate account of changes due to growth and orthodontic treatment, implants were inserted into individual bones. The implants served as reference points which can be easily identified and located.

Bjork[10] used a minimum of three implants in each jaw so that if one should shift position, it would be recognized. He identified four possibilities that would allow implant movement. Pins that did not completely enter the bone would be subject to periosteal drag and those placed in the path of erupting teeth or resorbing bone surfaces would be displaced.

The fourth possibility of implant movement, connective tissue reaction, was discussed by Morris.[11] His histological examination revealed that the connective tissue capsule around the implants was only 400 microns thick which is not enough room for the implants to tumble.

Bickler[12] undertook a computer-aided study of implants measured on radiographs and found that maxillary implants were significantly more stable after a period of time which averaged 10.4 months. He also found that the palatal and posterior zygomatic implants were more stable than the one placed in the anterior portion of the zygomatic arch.

The purpose of this investigation was to use the implant method to study the changes in the position of the maxilla relative to the sella-nasion plane and to determine the error associated with this computer-aided technic.

REVIEW OF THE LITERATURE

Early experiments using implants to study growth were done by direct measurement of the implants before and after the desired elapsed time. Stephen Hale[11] (1727) is credited with being the first to use metal markers to observe bone growth. He was able to detect appositional rather than interstitial growth in the tibia of a chicken. The famous anatomist, John Hunter (1728-1793), used a combination of lead shot and a vital dye to study the growth of a pig's tibia.

Gans and Sarnet[13] showed the implant method was viable for studying the growth of facial bones. They used direct measurement of amalgam markers which were placed on either side of important midface sutures in monkeys.

Debrevil[14] was the first investigator to use the radiographs in conjunction with metal markers for the study of bone growth.

The implant method for studying human facial growth was developed extensively by Bjork who, in 1955, submitted a preliminary paper describing methodology and case reports of five individuals.[15] Bjork used three chrome cobalt pins in each jaw. He felt two would suffice for the purpose of x-ray growth analysis, but three or four may be applied to safeguard against an implant shifting position without being detected. Growth vectors were illustrated by superimposing drawings of the films on the implants in each jaw.

In 1963, Bjork[10] reported on the growth of the mandibles of 45 boys. He had switched to tantalum implants, first used in humans by Bunnel,[16] due to their relative inertness compared to the chrome cobalt pins. He found a range of direction of condylar growth of 65 $^{\circ}$ relative to the mandibular plane and the extent of remodelling of the external contours was revealed. Vertical condylar growth was accompanied by compensatory resorption in the region of the angulus and apposition below the symphysis with the teeth erupting in a forward direction. Mandibles with condylar growth in a sagittal direction exhibited apposition in the angulus region with the teeth erupting in a posterior direction.

In 1966, Bjork[8] reported using the implant method to reveal the extent of sutural growth and periosteal remodelling in the male maxilla. The degree of remodelling was so extensive, he felt there was no stable, natural reference point for growth determinations. The sutural growth direction was unpredictable, having a range of 82.$^{\circ}$ However, there was a trend towards early saggital growth of the upper face followed by vertical growth in the adolescent years.

Implants have also been used to study the effects of mechanical force in the human maxilla to overcome the difficulty in finding fixed reference points. Krebs[9,17] used chrome cobalt markers in the basal and alveolar bone to study the effects of rapid palatal expansion. He found a combined basilar and dento-alveolar movement, the latter predominating in older patients.

Isaccson and Murphy[18] inserted endodontic cones into the maxillas of patients being treated for cleft palate. The effect of rapid expansion was unpredictable in the five patients studied.

Thornburn[19] described the method of placing intra-osseous metallic implants at the University of Oregon Dental School. Tantalum-tungsten .022" wire was cut into 1.5 mm lengths and inserted subperiosteally. In the mandible, they were placed in the mental fossa between the roots of the central incisors, below the first molar and on the anterior border of the ramus. In the maxilla, the implants were placed in the anterior and posterior areas of the zygomatic process and palatal to the second bicuspid.

It has therefore been shown that cephalometrics, coupled with the implant method, is a valuable technic for studying the effects of growth and orthodontic treatment on the bones of the face.

METHODS AND MATERIALS

A sample of Angle Class II females was selected from a group of patients who had been implanted and treated orthodontically at the University of Oregon Dental School. All of the subjects were fitted with a Kloehn cervical headgear and instructed to wear it 12 to 14 hours per day. Class II elastics were utilized for a brief (three month) period of time.

All subjects had three implants placed in each jaw and retained them throughout the duration of serial cephalograms. A minimum of four cephalograms covering a period of at least 30 months was required; however, many of the subjects exceeded these criteria. The average number of films for each patient was 5.4 with the limits of the range 4 to 7. The average number of months represented was 70 with a minimum of 31 and a maximum of 156. Twelve and one-fourth years was the average age upon commencement of treatment.

Four fiducial points were punched on each film to allow the computer to orient successive tracings of each film, after the method of Baumrind.[20]

The positions of points sella and nasion, the implants and the fiducial points were determined and recorded by a digitizer utilizing microphones sensing a high frequency spark. Each film was digitized three times to allow a mean to be produced for each point.

In order to determine the error involved with this technique, the radiographs of time point two were redigitized at a separate sitting. In addition, redigitized radiographs of another sample was compared to a previous report.[12] A comparison of each set of data superimposed on the fiducial points gave an indication of intraoperator and interoperator error (see Table I).

A program was written that directed the computer, a PDR 170 utilizing a UNIX operating system, to superimpose the serial radiographs on point sella and the line sella-nasion.

Since the implants cannot be placed in the same sagittal plane, they were subject to distortion which accounts for more error in the cephalometric technique. In order to reduce the error from this source, the computer employed a radiographic magnification, shrinkage and head rotation procedure called scaling. In this, the implants were uniformly expanded or contracted together until a least squares situation was achieved. It is thought that the above procedure compensates to some degree for cephalometric error due to the differences in head positioning in subsequent radiographs.[12]

The center of mass or geometric center of the maxillary implants was determined by bisecting each angle of the triangle created by three markers and computing the point of intersection. The change in position of the center of mass was determined for each film relative to the previous one as well as the initial film in each patient series. The change was reported as a vector, giving the magnitude in millimeters and the direction in centigrade degrees. The movement of the center of mass relative to the superimposition point was recorded on graph paper (Appendix I).

The average change of the center of mass of the implants was computed for both the treatment and posttreatment time periods and reported as a vector (see Table II).

FINDINGS

The displacement of the center of mass during orthodontic treatment, which averaged 32 months, was 1.24 mm in a direction 97° below the line S-N. After treatment was discontinued, the average vector of change was .39 mm at 68.7.$^{\circ}$ Of the 20 females in the treatment group, 18 were followed after removal of their orthodontic appliances for a period of time averaging 31 months (see Table I).

As expected, the interoperator standard errors of the measure (S.E.Meas.) were larger than the intraoperator values for all the landmarks studied. For point nasion, interoperator error was 1.51 mm which was more than the intraoperator 1.02 mm. Point sella had an interoperator S.E.Meas. that was .61 mm while the intraoperator value was .29 mm. The combined error of the implants was determined to be .98 mm for the interoperator computation and .24 mm for the intraoperator value (see Table II).

The S.E.Meas. for point nasion was further analyzed by determining the vertical and horizontal contributions to the total.[20] It was found that the S.E.Meas. in the Y axis (perpendicular to the line S-N) was .21 mm while the X axis value was much greater at .99 mm.

DISCUSSION

Possible sources of error in the cephalometric technic coupled with implant utilization are:

1) patient movement and the inability to accurately reposition the patient in the cephalostat.
2) distortion.
3) growth and remodelling of the superimposition areas.
4) implant movement.
5) operator errors of identification.
6) limitations of machine precision.

Because the radiographic images of the implants and landmarks used in this study were subject to distortion, a small change in head position during subsequent films may lead to a large change in landmark position.[22] Bjork[21] used an image intensifier and a television monitor to accurately reposition the patient in the cephalostat before each film was exposed. In this study, because the implants did not maintain a perfect relationship to each other in serial cephalograms, the computer employed the technic of scaling to overcome error due to changes in head position and distortion. In a previous study by Bickler,[12] this procedure led to significantly smaller error residuals for the implants and was thought to overcome to some degree the inability to accurately orient the patient's head. However, the validity of scaling has yet to be proven.

Growth of the pituitary leading to remodelling of sella turcica has been observed as apposition on the tuberculum sella and resorption on the posterior surfaces.[21,23] Undetected changes in the superior and posterior direction would be manifest as a downwards and forwards displacement of the maxilla which may be falsely attributed to natural growth or treatment-induced changes. The amount of remodelling of sella turcica has not been determined. The derived point sella was used in this study due to its apparent reproducibility and popularity as a reference point.

Nasion, while moving forward due to growth, may be displaced slightly upwards or downwards.[21]

Of course, cranial base implants would be the most desirable reference points from which to study facial changes but they remain impractical.

Implant movement due to connective tissue reaction, being in the path of an erupting tooth or a resorbing bone surface and being subject to periosteal drag, is a possible source of error. None of the implants were lost by the patients in this sample due to the criteria of subject selection. The problem of connective tissue reaction has been previously discussed [11] and the technic of implant placement should avoid the tendencies of periosteal drag.[19]

Significant differences ($p < .05$) of inter- and intraoperator S.E.Meas. of point sella and upper implant 1 show that there were differences between operators in terms of defining and being able to pinpoint these landmarks.

The definitions used in this study are as follows:

1) Nasion: the vertical center of the anterior edge of the fronto-nasal suture.
2) Sella: the geometric center or center of mass of sella turcica.
3) Implants: the superior end of the implant with reference to a grid system formed by the line S-N and its perpendicular. If the implant lays parallel to the line S-N so that its superior end could not be determined, then the right end was used as the implant location.

The above definitions lent to consistency in pinpointing landmark position but individual interpretation yielded some variation.

The largest S.E.Meas. was for point nasion (1.02 mm) which may be due to overlapping of hard tissue structures as well as its shape. The breakdown of the X and Y components reveal that the vertical position of point nasion was determined with greater repeatability than the horizontal component. This may be due to the triangular shape of an open fronto-nasal suture with the apex pointing posteriorly resulting in more length in the horizontal plane than the vertical. This left more room to error in the X axis, which was .99 mm, compared to the .21 mm S.E.Meas. in the Y axis. This increased the validity of the measurements since the vertical component of point nasion was used to establish the line sella-nasion. The horizontal error, which was the major portion, had very little influence on the validity of the superimposition system.

Point sella had a much lower S.E.Meas. (.29 mm) than point nasion, showing a greater ease of reproducibility of that point.

The most anterior maxillary implant was selected as the representative implant for comparing inter- and intraoperator measurement of implant location. The significant difference ($p < .05$) between the two S.E. Meas. revealed that operators had different perceptions regarding the location of the landmarks. Two possibilities for different opinions existed. The first was that each operator determined how much of the implant end he or she covered with the digitizer. This may have lead to minor systematic interoperator error.

A second problem was with an implant that was observed to be close to the horizontal position. If it was slightly elevated at the posterior end, the operator would have to choose that end according to definition. However, if the same operator at a different time or another operator judged the implant to be horizontal or elevated at the anterior end, he would have chosen the right end. Since the implants were 1.5 mm long, this represented a possibility for considerable intraoperator and interoperator error.

The high frequency spark digitizer used in this study had a range of error of .1 mm.[22]

Vector Analysis

The treatment and posttreatment vectors were significantly different ($p < .05$) in terms of magnitude but not direction. The treatment vector of 1.24 mm at 97.0° (centigrade) exceeded two standard errors of the measure which allowed it to be regarded as a statistically significant change according to some authors.[20] The clinical significance of this amount is questionable.

Two possibilities existed for creating the change in position of the maxilla as represented by the implants: natural growth and orthodontic treatment inducing an orthopedic change.

During the average treatment phase, between 12.75 years and 14.75 years, the 20 girls were past the peak growth spurt observed in adolescent females but still in the age range where significant facial changes have been documented.[25,24] This growth, directed predominantly downward, may have accounted for the change in maxillary position.

The other factor present in the sample, orthodontic treatment, entailed assumed Kloehn headgear along with various amounts of Class II elastic wear. These appliances would have placed a distal and inferior force on the maxillary teeth which may have been transmitted to the maxilla inducing an orthopedic effect. The orthopedic effect of Kloehn headgear has been substantiated in earlier headgear studies,[26] but the clinical significance has not been established.

In this study, lacking an untreated sample of growing females with implants for comparison, it was impossible to distinguish the contributions of orthodontic treatment and natural growth to maxillary change.

After treatment there was no significant change in the position of the maxilla with reference to the superimposition system. The average movement of .39 mm barely exceeded the measurement error of the landmarks. This finding is in agreement with current thought that females, on the average, undergo little change in their facial structures after the adolescent growth spurt which ends at approximately 15 years.[6,24]

Since the magnitude of change was so small, the angle of the post-treatment vector, 68.7 ^{o} (centigrade),was meaningless.

SUMMARY

1. Twenty adolescent females, with implants placed, had cephalograms taken during and after orthodontic treatment. The serial cephalograms were digitized and movement of the maxillary implants relative to the line sella-nasion was computed.

2. Analysis revealed a significant difference ($p < .05$) between treatment and posttreatment vector magnitudes but not directions.

3. Both intraoperator and interoperator standard error of the measures were computed for all landmarks used in this study. Point sella had the lowest interoperator S.E.Meas. while the implant locations were found to be the most reproducible landmarks by the same operator.

4. To establish clinical significance of the findings, it would be necessary to compare the orthodontically treated sample with an untreated sample.

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TABLE I

Vector Analysis

Group	Magnitude (mm)	Direction	N
Treatment	1.24	97.0	20
Posttreatment	.39	68.7	18
t (unpaired)	3.19**	1.14	38

TABLE II

Standard Error of the Measure (S.E.Meas.)**

A. Interoperator

Landmark	S.E.Meas. (mm)	N
Point sella	.61	15
Point nasion	1.51	15
Implants	.98	87

B. Intraoperator

Landmark	S.E.Meas.	N
Point sella	.29	21
Point nasion	1.02	21
Implants	.24	127

C. Statistical differences between interoperator and intraoperator S.E.Meas. (paired t test, N < 30)

Landmark	t
Point sella	5.07***
Point nasion	1.53
Implants	2.36*

**S.E.Meas. = $\sqrt{\frac{\Sigma(X)^2}{2N}}$

APPENDIX

Sample Calculation of Patient DB

A. Treatment Change

Initial coordinates (X, Y) = 45.61, -53.67

End of treatment = 45.02, -55.10

$\Delta X = X_2 - X_1 = 45.02 - 45.61$

$= -.59$ mm

$\Delta Y = Y_2 - Y_1 = -55.10 - (-53.67)$

$= -1.43$

Vector magnitude $= \sqrt{(\Delta X)^2 + (\Delta Y)^2} = \sqrt{(-.59)^2 + (-1.43)^2}$

$= 1.55$ mm

Vector direction (centigrade degrees) $= 90^\circ + \theta$

$= 90^\circ + \tan(.59/1.43)$

$= 90^\circ + 22.4^\circ$

$= 112.4^\circ$

B. Posttreatment Change

End of treatment coordinates = 45.02, -55.10

End of study coordinates = 45.57, -55.15

$\Delta X = X_2 - X_1 = 45.57 - 45.02$

$= .55$

$\Delta Y = Y_2 - Y_1 = -55.15 - (-55.10)$

$= -.05$

vector magnitude = .55 mm

vector direction - 5.2 $^{\circ}$

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TIMEPT	ANGLE	DIFF FROM FIRST TP	DIFF FROM PREV. TP	CENTROID X	CENTROID Y
1	-20.232	0.000	0.000	45.610	-53.670
2	-17.056	3.177	3.177	45.030	-55.010
3	-19.678	0.554	-2.623	44.430	-55.073
4	-20.829	-0.596	-1.150	45.023	-55.097
5	-20.209	0.023	0.619	45.570	-55.150

DIST FROM FIRST CENT	ANGLE FROM FIRST CENT	DIST FROM PREV. CENT	ANGLE FROM PREV. CENT
0.000	0.000	0.000	0.000
1.460	-113.405	1.460	-113.405
1.833	-130.059	0.603	-173.974
1.547	-112.353	0.594	-2.252
1.481	-91.548	0.549	-5.572