THE THEORETICAL RELIABILITY OF A THREE-DIMENSIONAL CEPHALOMETRIC TECHNIQUE STUDIED INVITRO

[redacted]

by

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INTRODUCTION

Cephalometric radiographs were first used by Pacini in 1922 for an investigation in the anthropometry of the skull. The purpose of the study was to serve the common objective of the "human evolution, development, transmission, classification effects, and tendencies of man's bodily and functional difference". The first comprehensive standardized cephalometric technique that was used in the field of orthodontics was in 1931 by Broadbent.

Through the past several years the cephalometric technique has grown from an isolated laboratory experiment to a valuable clinical and research tool in daily use by many practicing orthodontists[1]. At the present time, the cephalometric film is very popular in orthodontic diagnosis and has become an important part of the general method of studying growth in vivo.

Cephalometric measurements are influenced by several different sources of error including those related to technique, equipment, and procedure; such as blurring, enlargement, distortion, position of subject, exposure factor, etc., as well as the operator's interpretation of the radiograph. However, it is difficult to locate the anatomical landmarks or the stable reference points to be able to superimpose the successive films in the study of growth or change. The method of superimposition of the films is involved with several different factors such as the difficulty of locating landmarks precisely, error in measurement, distortion, etc. The problem of locating landmarks was improved upon by Björk[2] in 1955. He introduced the use of tantalum implant in the jaw as an attempt to obtain a more stable reference point.

For practical purposes, cephalometry still remains a two-dimensional method being applied to a three-dimensional subject. The problem of representing landmarks in a three-dimensional system has been resolved by Schwartz, Savara, and Dehan. They developed a three-dimensional cephalometric techinque on two films which improved the error from distortion of a three-dimensional object to a two-dimensional film. These techniques have proven reliable in cross-sectional research.

Sorenson and Hixon improved the three-dimensional cephalometric technique by using only one film and two concurrent exposures[3]. The reliability and validity of this technique was investigated by Cruikshank and Nixon[4] in 1970. The reliability of this technique has been improved by several researchers; Quino in 1972 used an implant phantom and analyzed the data by a programmable desk calculator and Dennis in 1972 analyzed the same data by a fully computerized program[5,6]. The validity was improved in that the variation of the head position during successive exposures did not affect the reliability of this technique.

Buck and Hodge in 1975 investigated the within-patient reliability of a three-dimensional cephalometric implant technique by using a mathematical rotation to transform the best fit of the geometric center of the triangular base described by the three implants in the initial and successive films[7]. The three implants that form the triangular base in their study were placed in the manner of Björk[2,38].

This paper will attempt to evaluate the reliability of the three-dimensional system by changing the relation of three implants in different triangular bases utilizing human skulls.

REVIEW OF THE LITERATURE

The cephalometer is one of the most important of all of the contributions made so far to the study of growth and development and to the science of orthodontics in general. Broadbent in 1931 provided the foundation for the standardized cephalometric technique employed today[8]. The improvement and investigation of the reliability of standard cephalometric technique have been done by several researchers such as Drs. Baumrind, Hixon, Miller, and Savara[9,10,11,12,13,14]. The search seems to continue at most all levels for a stable reference point and a method of measurement that can be used during growth for superimposition cephalometric tracing. There are however, many factors which contribute to the inaccuracy of cephalometric radiographs.

Thurow in 1951 pointed out the rule of thumb "The change in dimension due to change in enlargement will not be more than $\frac{1}{10}$ the change in subject-film distance"[1]. This enlargement can be corrected by simple geometric calculation. Enlargement is usually somewhere between 5% and 8% for a saggital point. However, it does not affect angular measurement or some proportions.

It does affect linear measurements and some proportions involving linear measurement. He also pointed out the causes of and corrections for blurring and distortion. Blurring can be caused by, 1) motion of subject or machine, 2) the size of the x-ray anode focal spot, and 3) grain, caused by intensifying screen and film[1]. Blurring can be minimized through controlling the motion of the subject or x-ray machine or by reducing the exposure time with intensifying screens and by using the highest milliamperage available. Optical blurring can be reduced by using the smallest possible anode target and by trying to get the subject as close as possible to the film. The accuracy of measurements will limit to about 0.5 mm by reducing blurring factors. Distortion is the result of differences in the amount of enlargement of different parts in the same picture. This can be corrected by using the midpoint between right and left points on the film[1].

Franklin[15] also suggested that the subject should be as close to the film as possible to reduce penumbra and enlargement. Horowitz and Hixon[16] pointed out that the enlargement of the midsaggittal plane can be reduced by about 6 - 7% by placing the subject approximately one inch from the film, and then having the target subject distance at 60 inches. Schwartz[17] in

1943, presented a method to correct for enlargement and distortion of distance between landmarks located on frontal and lateral cephalograms. Savara[18] improved Schwartz's method by placing 1 mm steel balls on the skull. Coordinates were then corrected for magnification and distortion by a transformation formula obtained from a computer program. He reported the difference between acutal and calculated distance ranged from -0.01 to +0.03 cm. Subsequent reliability studies have shown that landmark location error in the system is five times greater than that due to measurement error[13,14].

Kaaber[19] used the modified Evald cephalostat with an oblique 45° projection and metallic implants to study the bone level of alveolar process in 15 people. He found that the error of method showed values between 0.13 and 0.19 mm in the lower jaw, and between 0.13 and 0.23 mm in the upper jaw. He indicated the mandibular measurements were more reliable than the maxillary because there were fewer overlapping structures to reduce image quality. Adam[20] also stated that the enlargement of the image depended on target-film distance. At a one foot distance a skull outline may be enlarged by as much as 60% and that at a three foot distance he can reduce the object outline error by at least 50%. However, five feet is the most feasible target-film distance. The statement sometimes made, that x-rays will get parallel at a distance of six feet, is not true.

One purpose of standardizing a cephalographic procedure is to produce the roentgenograms from which accurate measurements can be made, as well as being able to superimpose successive films with confidence. Hixon[21] traced three lateral headfilms twice and eight other independent investigators made one tracing per film. By using Downs analysis[22] for certain cephalographic measurements, he found range of disagreement in one patient to be a 14.2 degree difference between the largest and smallest mandibular plane angle recorded. He also stated that the lesser disagreements occur with the same person repeating the tracings when they are done independently with a time interval of two days or more. Broadway, Healy, and Poyton[23] studied the accuracy of cephalogram tracings by using two tracers to trace 40 lateral cephalograms. He found that some cephalometric angles are more reliable than others. The standard deviation of difference between successive measurements of the same angle varied from 1.05° (SNB) to 3.14° (I-SN) for a single tracer and from 1.44° (SNB) to 5.54° (I-SN) for different tracers. Björk[24] has demonstrated that distances between landmarks have great variability in their reliablitiy, i.e., the standard error of measure of the S-N line is 0.30 mm where as the S.E. measure of distance between Bolton Point and Orbitale is 2.84 mm. He also found that the S.E. measure ranged from 0.26° to 2.43° for angular measurements, and from 0.27 to 2.84 mm for linear measurements.

Potter and Meredith[25] compared two methods of measurement; the first method was a direct measurement of the child; and the second involved radiography and measurement of the roentgenogram. They found that: 1) biparietal diameter is measured with high reliability by both methods, 2) bigonial diameter is measured more reliably by the roentgenographic procedure than by direct measurement. Thay also found that measurement error was limitied to ± 0.3 mm and ± 0.5 mm for bigonial and biparietal dimension when measured from one frontal head film by two measurers.

Baumrind and Frantz[9] investigated errors of linear and angular measurements by using 16 common landmarks on 23 cephalograms. They found that the magnitude of errors varied widely among the measurements depending on the different locations of the points, and that all points were not equal in their reliability. It appears that both the absolute values of errors and the variability among replicated estimates tend to be greater for angular measurements than for linear measurements. Björk and Solow[26] also pointed out that when a landmark is reused for measurements, its error contributes to the values for both measurements.

In addition to the error of measurement and tracing, the analysis of serial radiograph required an area of reference to superimpose successive tracings to assess changes due to growth or treatment. Various methods have been used for superimposition. Although the use of Frankfort-horizontal plane for superimposition had been generally accepted since 1882, its poor reproducibility in the cephalograph has prompted a search for an alternate reference. Koski[27] found that this plane is unreliable because the error of measurement exceeds the acceptable limit. Broadbent[28] used the point midway on the perpendicular from the Bolton-Nasion plane to Sella turcica as a registration point in superimposition of tracing from successive films. He found that the Bolton-Nasion plane and its registration point in the sphenoidal area is the most fixed point in the head or face. Brodie[29] used a method of superimposition different from that employed by Broadbent (he superimposed on the line Nasion to Sella turcica). He studied the growth pattern of the human head from the third month to the eighth year. He measured the distance between points, and angles between lines in tracings made form cephalometric roentgenograms. His method of approach was a quantitative one. In Björk's[30] study of cranial base development, he considered S-N line as remaining relatively constant between the ages of 12 to 20 years. Ford[31] and Bergersen[32] also supported the use of S-N line as a reference line for superimposition. Steue[33] in 1972 found that it is acceptable to use cranial surface of sphenoid bone for superimposition.

However, there appear to be no absolute stable points of reference to be found on a serial basis in the growing craniofacial complex. Superimposing even the most technically excellent cephalograms remains a process of relating an unstable area or structure to one that is more stable. Björk[34] in 1969, reported the relative stability, not absolute stability, of structures during growth such as the tip of the chin, the inner cortical structure at the inferior border of the symphysis, the trabecular structures related to the mandibular canal, and the lower contour of a molar germ until the roots begin to form. Therefore, it is impossible to have stable fixed anatomical reference points. The problem of superimposing was resolved by

Björk[2] by using metallic implants to study facial growth in man by placing metallic implants in the maxilla and mandible to serve as reference points. This system allowed him to record growth increments within the limit of ± 0.5 mm[35]. There are many factors involved in implant stability, such as technique of implantation and the fibroblastic activity of bone to the implants. Morris[36] studied histologically the reaction to implants of tantalum and other metals and found that tissue reactions were shown by macrophage and osteoblastic activity, degradation of adjacent cells, and the formation of a collagenous capsule around the tantalum implants.

Accurate head repositioning is very important to the implant technique. Steiner[37] stated that even when the head is mounted on the ear posts of the cephalometer, movement still occurs in varying degrees. Björk[38] used a cephalostat with a built-in 5 inch image intensifier allowing television monitoring to improve accurate head repositioning before the exposure is made.

Sorenson and Hixon[3] introduced a three-dimensional cephalometric technique using two x-ray machines angulated and directed at one lateral head film This technique was investigated by Cruikshank and Nixon[4]. By taking simultaneous exposures of a dried skull which had three implants on the mandible, they were able to calculate the distances between the markers placed on the lower left molar and cuspid teeth. They found that the average error was 0.5 mm between and within films.

Quino[5] re-investigated the above system by using a plastic implant phantom. Ten films were taken with different model positions. The distances between the implants were calculated by a programmable electronic desk calculator. He found that the difference between the actual and the calculated marker movement was 0.38 mm. Dennis[6] continued the study by adapting the data in a manner to utilize a computer program. He was able to show that at the confidence limits ($\alpha = .01$) the changes in landmark position between subsequent films which are greater that ± 0.2 mm in the x axis, ± 0.4 mm in the y axis, and ± 0.5 mm in the z axis would represent a real change.

Buck and Hodge[7] investigated the within-patient reliability of this method by using acrylic templates with 0.5 mm diameter amalgam markers that were formed to the maxillary and mandibular central incisors on each patient who had been previously implanted with three tantalum implants in the mandible and maxilla. The standard errors of the method were ± 0.255 mm for maxilla and ± 0.222 mm for mandible. Any movement which exceeded .078 mm in the maxilla and .067 in the mandible represented a real change at the $\alpha = 0.01$ confidence level.

MATERIALS AND METHODS

Using the relationship of three implants to each other, six different triangular bases were set up on three dried human skulls. Each maxilla and mandible was set up with three different triangular bases. In each of the three mandibles, three implants were placed to form a triangle A, triangle B, and triangle C. These implants were placed with a speical pencil-shaped instrument in the tip of which the implant is placed[2,38]. (Fig. 1) The implants were hard tantalum pins with a diameter of 0.37 mm and a length of 1.2 mm. In addition to the implants there were small metallic spheres (1 mm diameter) used as the markers. These metallic balls were cemented to the labial surface of both maxillary and mandibular right central incisors.

In triangle A, the three implants were placed: 1) at the symphysis on the labial surface inferior to the apices of the mandibular central incisors, 2) on the buccal surface inferior to the apex of mesio-buccal root of the right mandibular first molar about the level of the mental foramen, and 3) on the external aspect of the ramus on a level with the occlusal surfaces of the molars.

In triangle B, the three implants were placed: 1) at the symphysis on the labial surface inferior to the apices of the mandibular central incisors (at the same place as the first implant of the triangle A), 2) on the buccal surface between the apices of mandibular right first and second premolars and above mental foramen level, and 3) inferior to the disto-buccal root of the right mandibular second molar, inferior to the second implant.

In triangle C , the three implants were placed: 1) at the symphysis on the labial surface between the apices of the mandibular central incisors, 2) on the buccal surface between the apices of mandibular right first and second premolars and above mental foramen level (at the same place as the second implant of triangle B), and 3) inferior to the disto-buccal root of the right mandibular last molar slightly inferior to the second implant.

In the maxillas, three implants were placed to form a triangle D, triangle E, and triangle F.

In triangle D, the three implants were placed: 1) at the right side of the median suture inferior to the anterior nasal spine above the level of the root apex of the right maxillary central incisors, 2) at the buccal surface superior to the disto-buccal root of the right maxillary first molar, and 3) at the hard palate behind the right maxillary central incisor.

In triangle E, the three implants were placed: 1) at the right side of the median suture inferior to the anterior nasal spine, above the level of the root apex of the right maxillary central incisors (at the same place as the first implant of the triangle D), 2) at the buccal surface about the apical level of disto-buccal root of the right maxillary first molar, and 3) at the hard palate behind the enbrasure between the right maxillary first and second premolars.

In triangle F, three implants were placed: 1) at the right side of the median suture inferior to the anterior nasal spine between the level of the root apices of the maxillary central incisors, 2) on the buccal surface about the mesial of apical level of the mesio-buccal root of the maxillary right first molar, and 3) at the hard palate behind the embrasure between the right maxillary canines and first premolars.

A cephalometer was constructed similar to the one described by Nixon and Cruikshank; two heads set equidistant from the plane of the film and horizontal in relation to each other. The first head was set up so that the central ray was perpendicular to the film and exposed only 2/5 of the 10 x 12 inch film. The second head was set up so that the central ray is at roughly 30 degrees angulation to the first head beams. (Fig. 2) The distance between the two x-ray machines, which were parallel to the film was 807.5 mm. The distance from the focal spot of the first head to the film was formed to be 1609 mm. The second head was collimated so that a simultaneous duplicate image of the structures exposed by the first head can be produced on the remaining 3/5 of the film. (Fig. 3) The Cartesian coordinate system was formed by the point where the central ray of the first emitter was set up to pass through the ear posts. This central ray formed the "Z" axis. The line that passes through the origin of the coordinate system and parallel to the line joining the two focal spots of the x-ray machine formed the "X" axis. The "Y" axis was constructed as a perpendicular to the "X" axis through the point of origin. The images of "X" and "Y" axes on the films were constructed by using .016 round wires mounted perpendicular to each other in front of the cassette holder.

The skulls were placed in the cephalometric head holder with individually made acrylic ear plugs. The first x-ray machine was set up at 50 ma, 85 KV, and 1/30 sec. The second x-ray machine was set up at 50 ma, 85 KV, and 5/20 sec. These two x-ray machines exposed the film simultaneously.

Two sets of film were exposed. In the first set eighteen exposures were taken for six different triangular bases in the three skulls.

Eighteen more exposures were taken in the second set after the skulls were removed from the head holder and then replaced for the second set of exposures without unusual attention to skull repositioning.

The measurements were made directly on the films with a John Bull caliper. The images of the implants and markers were pin-pricked with a sharp pointed Venier caliper. (Fig. 4) Five measurements (Fig. 5) of each implant and marker in the initial film were entered as the input (Fig. 6) for the computer program. These same measurements were repeated on the successive films and entered together. Each distance was measured to the nearest 0.01 mm. The output (Fig. 7) describes the position of the implants markers within the coordinate system, the closeness of fit of the triangular bases, and the movement of the markers[39]. Sixteen films were chosen randomly and remeasured for the standard error of measurement. The calculation which served as the basis for the computer program can be found in Buck and Hodge's study[7].

FINDINGS

In order to evaluate the reliability of the three-dimensional system, changes in the relationship of three implants in different triangular bases were made. The standard error of the method was calculated (Table 1). These errors included the errors of landmark location, the errors of measurements, and other technical errors. The standard error of the method for the maxilla = ± .19 mm, and the mandible = ± .41 mm. The error in each of the coordinate systems was also computed. The standard error of the estimate of computed linear distances between the maxillary and mandibular implants (ΔAB, ΔBC, ΔAC) was obtained from the two films taken twice with the fixed implants (Table 2). In the maxilla the standard error in the AB distance and in the AC distance was greater than those same distances in the mandible. The standard error of the BC distance was, however, greater in the mandible.

For the standard error of measurement 16 films were randomly selected and one distance per film was measured (Table 3). Points from which these measurements were made had already been pin pricked. The duplicate measurements were taken with a John Bull dial point caliper as were the originals. The standard error of the measurement ($\frac{\Sigma D^2}{2N}$) was found to be .028 mm (Table 3).

The standard error of the estimate of linear distances between the implants A, B, and C in triangles with different bases was calculated for each triangle (Table 4). The standard error of the estimate of linear distances was less for distances AB and AC in triangle A, while in triangle C the BC distance had the smallest standard error of the estimate of linear distances.

DISCUSSION

The arrangement of the implant positions in a patient so as to yield the best possible accuracy when using a three-dimensional cephalometric technique was investigated.

The standard error of measurement was .028 mm which was well within the fiducial limit ($\alpha = .01$) of ± .10 mm which Hodge considered to be the greatest allowable amount of error.

The standard error of the estimate of linear distances between the implants showed that in two out of three (for AB and AC) of the standard errors were less in the mandible than in the maxilla. A possible explanation might be the sample size in the mandible is less than the maxilla because of an error in key punching data. The errors were still less than those of Hodge's fiducial limit. From this we may conclude that the shape of the triangle is not so critical as to negate the results of a study on that basis alone. This does not imply, however, that a triangle does not exist that would allow for a reduction in this type of error.

The standard error of the estimate of linear distances between the implants showed that triangle A had the smallest error and triangle B had the greatest error. Triangle A, it should be noted, was also the triangle that most closely resembled an equilateral triangle and triangle B being the triangle used in this study that was least like one with the remainder of the triangles falling in between these two extremes but still following the same pattern. Because of the small number of variations in the shape of the triangles that were used, it is not possible to state that the amount of error shown in triangle A cannot be reduced further by another shape. This question would need to be resolved by further investigation. The small sample size of the skulls used may also cast doubt as to whether these findings would remain true in a broader variety of anatomical shapes.

SUMMARY AND CONCLUSION

Six different triangluar bases were set up on three dried human skulls with the maxilla and mandible each having three different triangular bases. Two films were taken for each triangular base in each skull using three-dimension cephalometrics. Five measurements were made by using a John Bull dial point caliper.

The reliability of the three dimensional cephalometric implant methods compared with the values established in Hodge's for the same system, showed that the standard error of the method was less than Hodge in the maxilla but greater in the mandible and that all of the results were within the fiducial limit established by Hodge.

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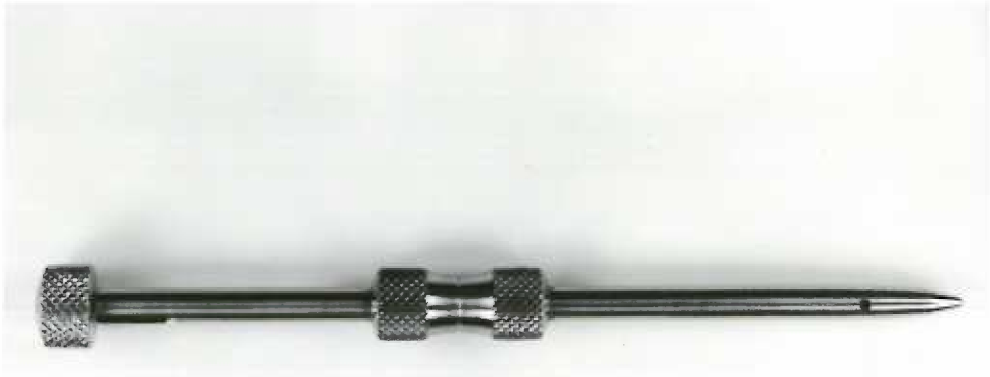


Fig. 1 Björk instrument for the placement of tantalum implants.

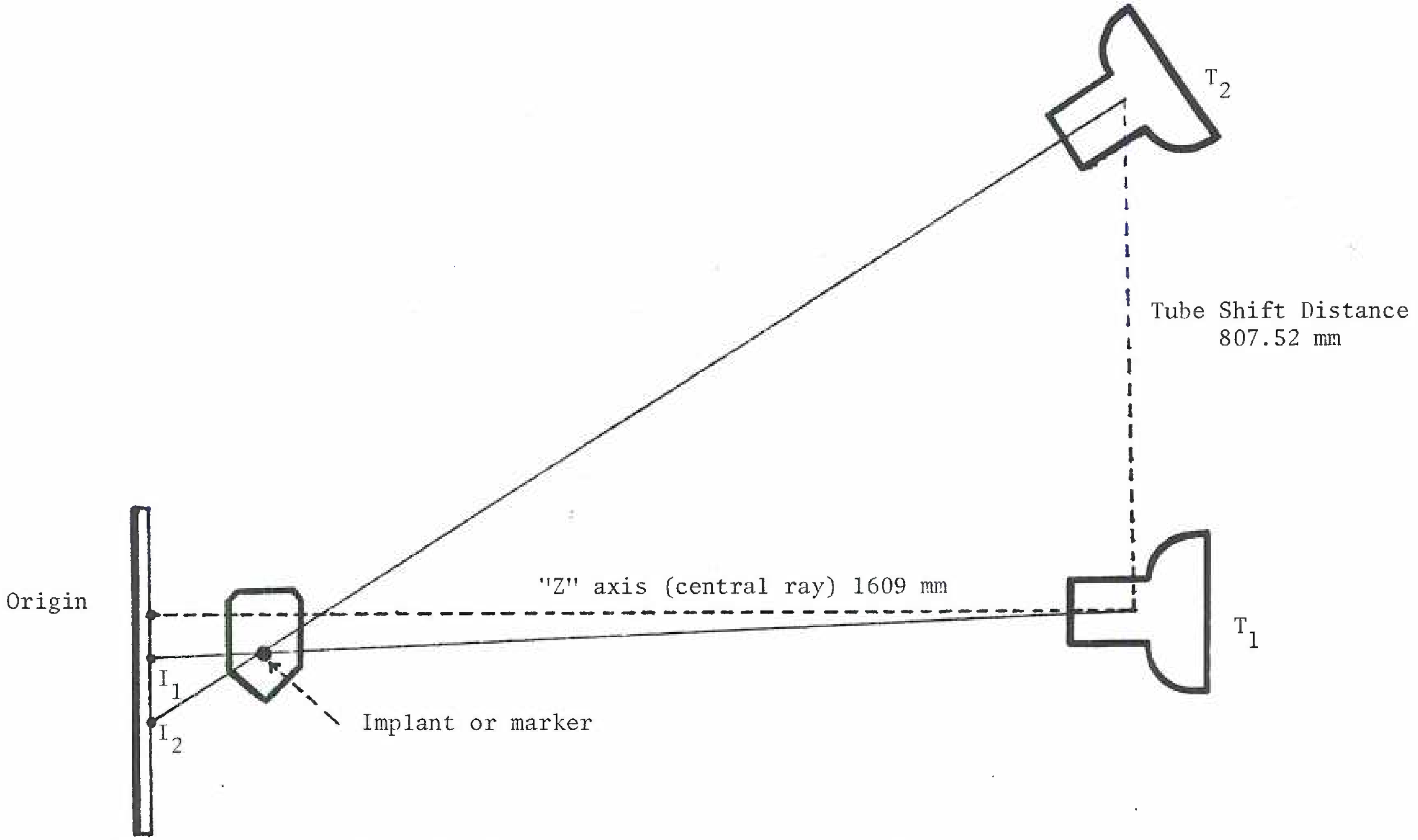


Fig. 2 Diagram of the three-dimensional cephalometric technique set up.

Fig. 3 X-RAY SET-UP

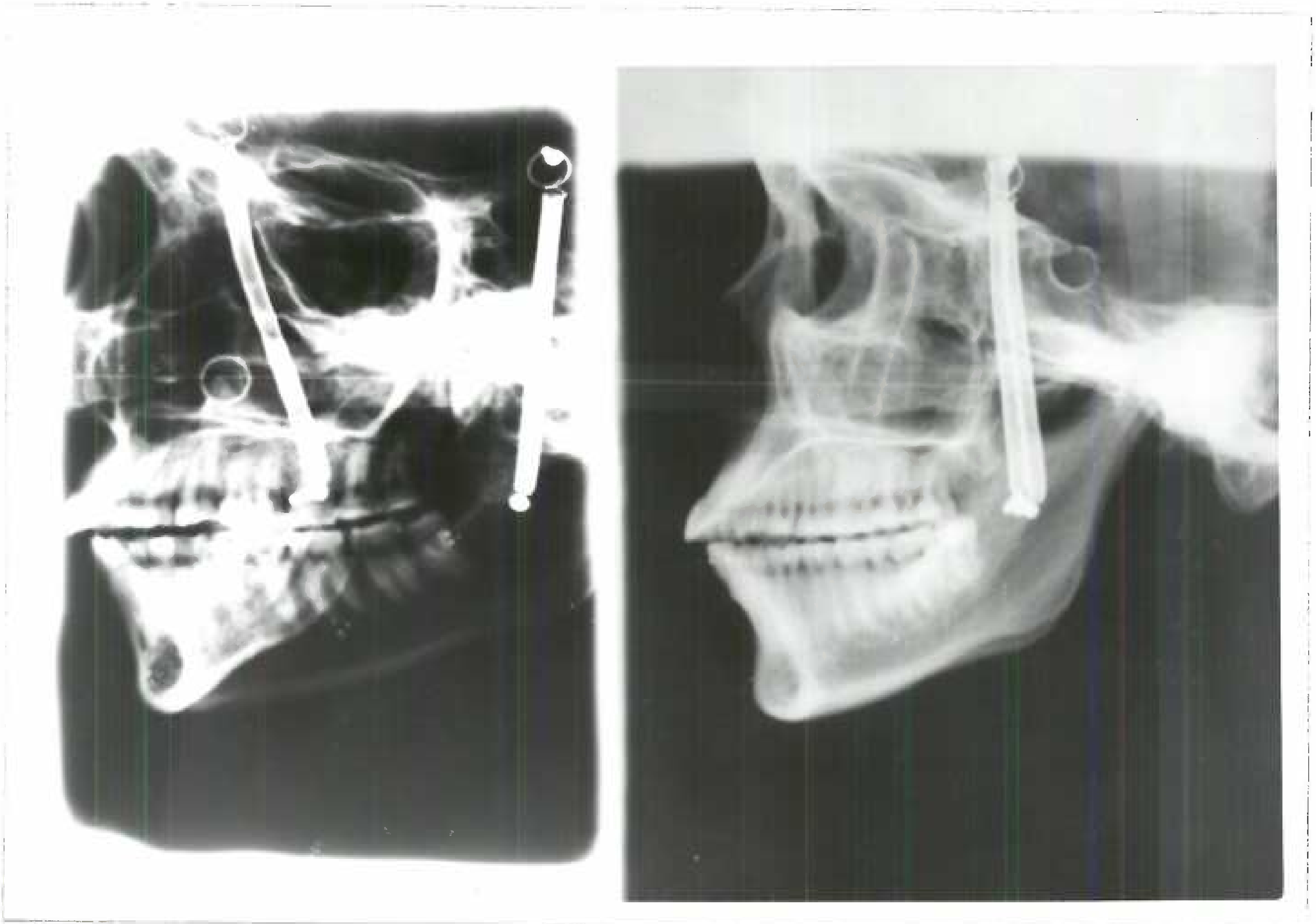


Fig. 4 RADIOGRAPH TAKEN BY 3-D TECHNIQUE

Image on left exposed by the angulated head. Image on right exposed by the head normal to the film.

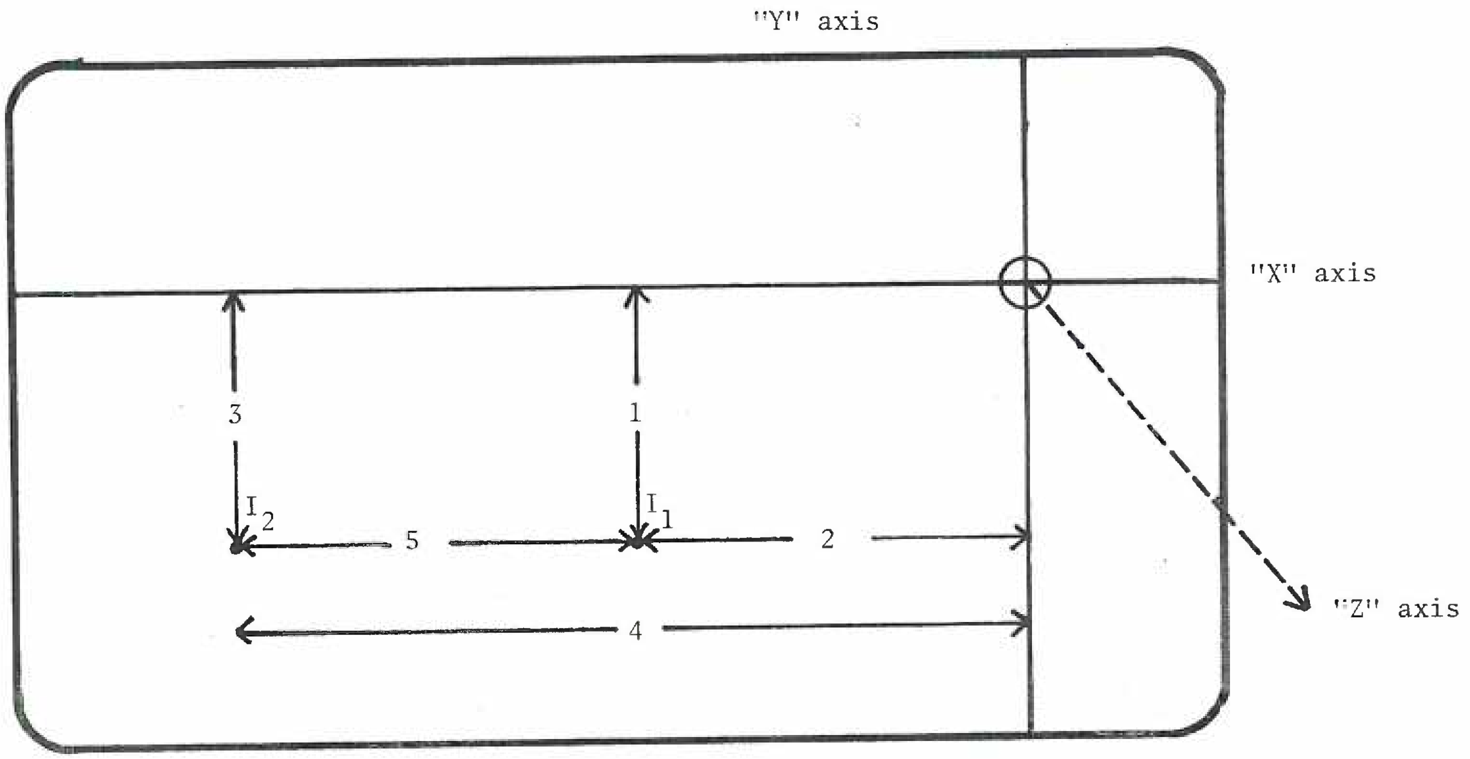
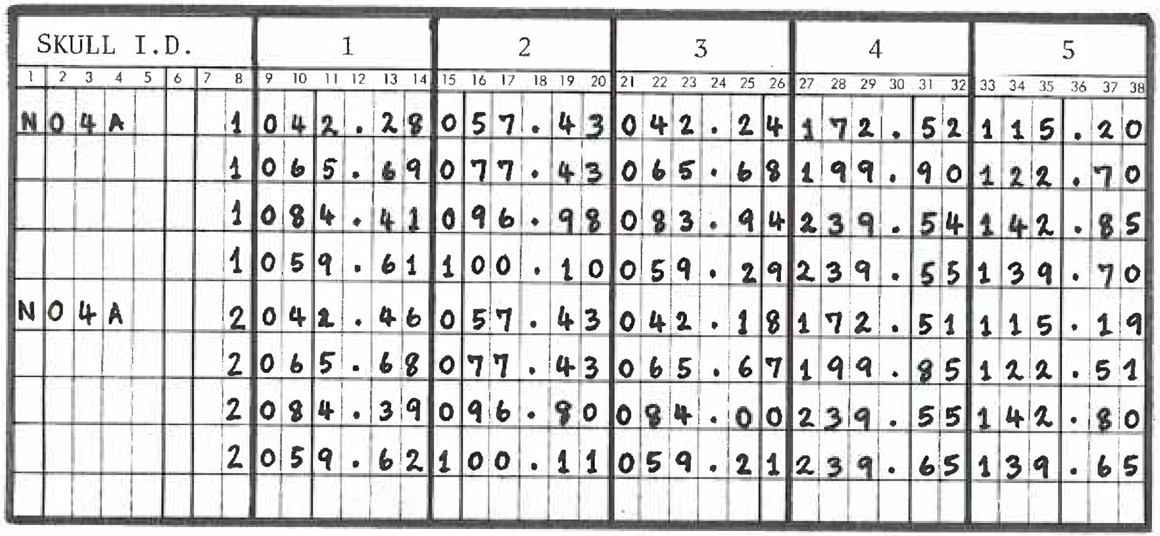


Fig. 5 Five measurements from the cephalograph of the dual images of each implant and marker.



SKULL I.D.		1	2	3	4	5		
1 2 3 4 5 6 7	8	9 10 11 12 13 14	15 16 17 18 19 20	21 22 23 24 25 26	27 28 29 30 31 32	33 34 35 36 37 38		
N04A	1	042.28	057.43	042.24	172.52	115.20	A	1st measurement
	1	065.69	077.43	065.68	199.90	122.70	B	
	1	084.41	096.98	083.94	239.54	142.85	C	
	1	059.61	100.10	059.29	239.55	139.70	I	
N04A	2	042.46	057.43	042.18	172.51	115.19	A'	2nd measurement
	2	065.68	077.43	065.67	199.85	122.51	B'	
	2	084.39	096.80	084.00	239.55	142.80	C'	
	2	059.62	100.11	059.21	239.65	139.65	I'	

Fig. 6 Input Sheet

```
                  3 D .   D O U B L E   F I L M   C E P H A L O M E T R I C S

                                        U N C O R R E C T E D

FIRST MEASUREMENT     NO4A        1                           SECOND MEASUREMENT      NO4A        2

CORD        A           B           C           I           A           B           C           I

X        50.260      67.210      82.400      85.330      50.260      67.230      82.250      85.350
Y        36.980      57.020      71.520      50.680      37.040      57.020      71.540      50.650
Z       200.900     212.290     241.920     237.370     200.880     211.970     241.790     237.260

                                          C O R R E C T E D

CORD        A           B           C           I           A           B           C           I

X        50.260      67.210      82.400      85.330      50.327      67.218      82.325      85.553
Y        36.980      57.020      71.520      50.680      37.055      57.057      71.408      50.586
Z       200.900     212.290     241.920     237.370     200.972     212.140     241.998     237.249

ERROR IN A =   0.123                       FIRST MEASUREMENT                          SECOND MEASUREMENT
ERROR IN B =   0.155
ERROR IN C =   0.156                       DIST AB = 28.612                           DIST AB = 28.463
RMS ERROR  =   0.145                       DIST BC = 36.317                           DIST BC = 36.410
MOVEMENT   =   0.270                       DIST AC = 62.519                           DIST AC = 62.348
DELTA X    =   0.223
DELTA Y    =  -0.094
DELTA Z    =  -0.121
```

Fig. 7 Output Sheet

TABLE I STANDARD ERROR OF THE METHOD

	ERROR MAXILLA					ERROR MANDIBLE			
	X	Y	Z	TOTAL		X	Y	Z	TOTAL
NO3D	.107	-.212	-.462	.519	NO3A	.295	.079	-.595	.669
NO4D	.033	-.582	.062	.586	NO4A	.223	-.094	-.121	.270
NO5D	-.440	.307	.720	.898	NO5A	.365	.047	.241	.439
NO3E	-.063	-.430	-.812	.921	NO3B	--	--	--	--
NO4E	-.292	-.121	.193	.370	NO4B	.160	.215	-.533	.596
NO5E	.069	-.096	-.335	.355	NO5B	.013	.003	.038	.041
NO3F	--	--	--	--	NO3C	.490	.275	-.540	.779
NO4F	-.254	.082	.395	.476	NO4C	-.686	-.081	.678	.968
NO5F	-.010	.175	.527	.556	NO5C	--	--	--	--
$\sqrt{\frac{\Sigma D^2}{2N}}$	.022	.040	.120	.191		.267	.101	.323	.431
From data of Hodge									
$\sqrt{\frac{\Sigma D^2}{2N}}$	.142	.073	.199	.255		.105	.070	.182	.222
Confidence limit									
α .05	.31	.16	.43	.56		.23	.15	.39	.48
α .01	.43	.22	.61	.78		.32	.21	.55	.67

TABLE II STANDARD ERROR OF THE ESTIMATE OF LINEAR DISTANCES BETWEEN IMPLANTS A, B, AND C

(Δ = 1st measurement - 2nd measurement)

	MAXILLA				MANDIBLE		
	ΔAB	ΔBC	ΔAC		ΔAB	ΔBC	ΔAC
NO3D	-.616	-.164	-.579	NO3A	-.077	-.356	-.372
NO4D	.060	.016	.030	NO4A	.149	-.093	.171
NO5D	-.298	.374	-.244	NO5A	-.004	-.355	-.138
NO3E	-.036	.141	.370	NO3B	-.156	.913	.488
NO4E	.326	-.368	.233	NO4B	.144	.007	.134
NO5E	-.018	-.003	.267	NO5B	-.199	.288	-.021
NO3F	-.613	.520	.188	NO3C	-.457	-.157	-.650
NO4F	.247	-.021	.232	NO4C	.235	.040	.297
NO5F	-.341	-.340	-.938	NO5C	--	--	--
$\sqrt{\frac{\Sigma D^2}{2N}}$	.250	.197	.296		.152	.273	.243
Fiducial limit from data of Hodge							
α .01	.41	.20	.44		.49	.34	.60

TABLE III WITHIN FILM RELIABILITY

No.	Random Measured	First Measurement	Second Measurement	Difference
1	5F2C1	33.71	33.72	-.01
2	3C1A2	48.79	48.80	-.01
3	4C2I5	139.85	139.80	.05
4	4D1I3	31.50	31.44	.06
5	4C1B1	63.08	63.11	-.03
6	4B2A1	55.85	55.85	.00
7	4B1C2	96.80	96.85	-.05
8	4F2A3	16.10	16.08	.02
9	4A2I1	59.62	59.67	-.05
10	4A1C2	96.98	96.92	.06
11	3D2I5	136.24	136.24	.00
12	3D1B2	94.98	94.91	.07
13	5D2B2	82.50	82.52	-.02
14	5D1A5	119.45	119.41	.04
15	5C1A2	57.19	57.19	.00
16	4B1B5	125.98	125.92	.06

Standard error of the measurement, $\sqrt{\frac{\Sigma D^2}{2N}} = .028$

TABLE IV STANDARD ERROR OF THE ESTIMATE OF LINEAR DISTANCES BETWEEN IMPLANTS A, B, AND C, IN EACH TRIANGLE

(Δ = 1st measurement - 2nd measurement)

TRIANGLE A	ΔAB	ΔBC	ΔAC
NO3A	-.077	-.356	-.372
NO4A	.149	-.093	.171
NO5A	-.004	-.355	-.138
$\sqrt{\frac{\Sigma D^2}{2N}}$	.060	.201	.170

TRIANGLE B	ΔAB	ΔBC	ΔAC
NO3B	-.156	.913	.488
NO4B	.144	.007	.134
NO5B	-.199	.288	-.021
$\sqrt{\frac{\Sigma D^2}{2N}}$	.117	.391	.201

TRIANGLE C	ΔAB	ΔBC	ΔAC
NO3C	-.457	-.157	-.650
NO4C	.235	.040	.297
NO5C	--	--	--
$\sqrt{\frac{\Sigma D^2}{2N}}$	.250	.070	.350

TRIANGLE D	ΔAB	ΔBC	ΔAC
NO3D	-.616	-.164	-.579
NO4D	.060	.016	.030
NO5D	-.298	.374	-.244
$\sqrt{\frac{\Sigma D^2}{2N}}$	.270	.160	.250

TABLE IV (cont.)

TRIANGLE E	ΔAB	ΔBC	ΔAC
NO3E	-.036	.141	.370
NO4E	.326	-.368	.233
NO5E	-.018	-.003	.267
$\sqrt{\frac{\Sigma D^2}{2N}}$	.130	.160	.201

TRIANGLE F	ΔAB	ΔBC	ΔAC
NO3F	-.613	.520	.188
NO4F	.247	-.021	.232
NO5F	-.341	-.340	-.938
$\sqrt{\frac{\Sigma D^2}{2N}}$	.300	.250	.402