A STUDY OF METHODS OF ESTABLISHING A MID-SAGITTAL PLANE IN POSTERO-ANTERIOR CEPHALOGRAMS

by

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Dedication

TO MY PARENTS

for so many good reasons

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INTRODUCTION

The lateral cephalogram is widely used by the orthodontic clinician as a diagnostic aid in his everyday practice; however, few if any postero-anterior cephalograms are being utilized. Limited use of the P-A film is due to the lack of a reference base from which bilateral measurements may be determined. The purposes of this study are first to compare measurements of facial and dental asymmetries obtained by the Harvold Method with those derived from a modified procedure and second to develop a modification of Harvold's technique for establishing a mid-sagittal reference base.

Since the P-A film reveals the two lateral halves of the brain case and face, a mid-sagittal plane of the skull makes it possible to assess the lateral position of the maxillary segments and also the lateral position of the mandible and other dentofacial structures. Such a plane, if reliable, should be a welcome addition to the diagnostic armamentarium of the orthodontist since pre-treatment recognition of asymmetries would permit better guidance in establishing right-left symmetry as well as anteroposterior corrections. Perhaps the periodontist would also find this plane of diagnostic significance for the investigation of deviated paths of mandibular closure. With these thoughts in mind it becomes evident that a mid-sagittal plane can be of great practical as well as theoretical value in the field of dentistry.

Using two different positioning methods in the Broadbent-Bolton cephalometer 40 postero-anterior cephalograms were made of 20 adult skulls. Identical bilateral craniofacial landmarks were measured by two different techniques with the use of a millimeter grid on the obtained postero-anterior cephalograms. Error studies were conducted on the positioning methods and the measuring techniques to determine if these sources of error were significant. The results of this study were subjected to statistical analysis.

REVIEW OF THE LITERATURE

Asymmetry may be defined as "lack of similarity or correspondence of the organs and parts on each side of an organism."[1] The study of bilateral asymmetries of the face and its skeleton has been of great interest to investigators for many years. Anatomists of the 19th Century were concerned with the problem of symmetry and as early as 1887 Hasse[2] examining the symmetry of Venus of Milo and the faces of living subjects found that facial asymmetry was a normal phenomenon.

In order to determine accurately the site and extent of facial asymmetry a mid-sagittal plane from which lateral measurements could be obtained had to be devised. A mid-sagittal plane may be defined as "a vertical plane drawn through the midline of the body that divides the body into right and left halves."[3]

Gnathostatics played an important role in making the orthodontist more conscious of such a diagnostic aid as a mid-sagittal plane in the recognition of facial imbalances and arch asymmetries.[4, 5, 6, 7] Simon[4] developed gnathostatics as a diagnostic medium relating the teeth and their bases to each other and to craniofacial structures. For the first time the denture was related to the face and cranium in three planes of space, i.e., the Frankfort horizontal, the Orbital plane and the Raphe or median sagittal plane.

Hellman[8, 9], Broadbent[10] and others[11, 12] called attention to variations of Simon's norms in many instances primarily because they

felt there was no true bilateral symmetry in the human head. The fact that facial asymmetry is quite common in otherwise normal adults is well illustrated in an article by Jackson[12], who, through the use of photographs assembled two left and two right sides of the faces of well-known personages.

In 1931 Broadbent[13] published a cephalometric roentgenographic technique designed to yield strictly reproducible X-rays of the head. He emphasized that this technique did not depend on measurements taken through the covering of soft tissues of unknown thickness, thus it was easier to arrive at the true dimensions of a skull from an X-ray film than from direct measurement of the skull itself. Once again investigators were given a new technique to enhance their study of the human head.

The dental literature and journals became flooded with uses both practical and theoretical for this new diagnostic tool and one is not surprised to see the problem of facial and dental asymmetry subjected to radiographic scrutiny. The lateral cephalogram was from the start far more interesting to the clinician whose main concern was the patient's profile and so the postero-anterior cephalogram was discussed but not utilized. Even now the syllabus by Krogman and Sassouni[14] describes more than 40 diagnostic methods, all of them concerning the profile cephalogram. The authors themselves state "Generally speaking in roentgenographic cephalometry, breadths and heights have been relatively neglected in favor of the anteroposterior or depth dimensional changes."

Thompson[15] in 1943, was perhaps the first to attach any real practical significance to the postero-anterior film. He conducted a

study on "abnormal" asymmetry of the face using P-A cephalometric roentgenograms, photographs and models. His mid-sagittal plane was determined by a perpendicular line bisecting the biparietal and bizygomatic measurements. In concluding his paper Thompson states, "Malocclusion is not one of the causes of asymmetry of the face, but rather one of the symptoms. The orthodontic treatment may straighten the teeth, but it will not straighten the face." Certainly this statement should direct the orthodontist's attention to the importance of the frontal film if he expects to establish right-left symmetry.

In 1945, Wylie[16] suggested to the dental profession that orthodontists and students of growth weren't the only ones who could profit through use of the cephalometer. He pointed out that the P-A film is particularly helpful in making a detailed study of patients with mandibular asymmetry, since all parts are projected to a single plane, and their relative positions in opening and closing are readily compared.

Potter and Meredith[17] conducted a study to compare and evaluate obtaining biparietal and bigonial measurements by use of a postero-anterior cephalogram versus direct measurement. Their findings indicated: 1) biparietal diameter is measured with high reliability by both procedures; 2) bigonial diameter is measured more reliably by the cephalometric procedure than by direct measurement.

In 1950, Woods[18] examined quantitatively the changes that occur in the width dimensions of the dental arches and certain facial

points during human growth using both lateral and postero-anterior cephalograms. This study also concluded that it is possible, with the aid of the Wylie compensator, to make accurate measurements from frontal cephalometric roentgenograms, provided the landmark to be measured can be located in both the frontal and lateral films.

Harvold[19] in 1951, presented what appears to be by far the most scientific investigation on the establishment of a mid-sagittal plane in postero-anterior cephalometric roentgenograms. His investigations showed that the upper vesiceral cranium is very symmetrically built. From these investigations Harvold proposed his so called "median plane" which is a reference base representing the median plane of the head. A line is first drawn connecting two points, FMT right (FMT_r) and FMT left (FMT_l), the most laterally situated points on the right and left sutures between the zygomatic and frontal bones. A second line, the median plane, is then drawn at right angles to the FMT_r - FMT_l line. This median plane passes through X registration point at the root of crista galli where it joins the cribriform plate of the ethmoid bone. Harvold's results indicated that in 90 per cent of cases the median plane divided the distance between the right and left zygomatic bones into two parts that differed by less than 3mm. In more than 90 per cent of the cases the anterior nasal spine was found to be less than 1.5mm. from the X-line, and when the distances were measured on both sides from the temporal border of the zygomatic bone, and from the zygomatico-maxillary sutures on the malar processes to the X-line, the index of symmetry obtained in this way closely corresponded to anthropometric

findings. Now it became possible with the aid of X-ray films to register asymmetries within the facial skeleton with a considerable degree of accuracy. This method of analysis then was used by Harvold[20] to record variations of symmetries in normal living material and special asymmetries which appear in connection with unilateral total cleft palates.

In 1955, Subtelny[21] in the study of the frontal X-ray film, assessed asymmetry using the foramen rotudum via laminography.

Sassouni[22], in 1958, proposed a mid-sagittal plane on the P-A cephalogram which was constructed by connecting the right and left latero-orbital points with a straight line and then drawing a line perpendicular to it from Nc (neck of perpendicular lamina of the ethmoid). The observer could then check all bilateral asymmetries on both sides of the perpendicular.

In 1960, Sassouni[23] presented another method by which facial and dental asymmetries could be noted on the P-A film. He suggested the investigator trace the supraorbital line, the Lo-Lo line, the bizygomatic line, the bimastoid line and the bigonial line. According to Sassouni, these lines should be parallel in an ideal situation. When they are not, he advised selecting as horizontal lines, the three out of five which are parallel. Then from their midpoint a vertical perpendicular can be dropped and assessment of the transverse symmetry of the teeth and bony contours obtained.

Berger[24] has reported on a third view in cephalometrics which until recently has received little if any attention, the basilar view. It is his feeling that the most obvious use of a basilar film would be the determination of a midline and the assessment of

asymmetry. There are a number of points which qualify for this purpose: the anterior tubercle of the atlas, the odontoid process of the axis and the outline made by the vomer and crista galli. In addition to these, two characteristic features on the inner walls of the frontal as well as the occipital bone can help in the determination of a midline.

A method of identifying, describing and evaluating dento-facial asymmetries has been proposed by Cheney[25]. His main interest centered on the use of points N and ANS as reference points in determining the mid-sagittal plane for direct observations about asymmetries. Direct observational procedures which entail lateral, frontal and inferior facial examinations were shown to be of significant benefit when dealing with facial imbalances and arch asymmetries.

The fact that facial and dental asymmetries are of importance in orthodontics as well as other facets of dentistry has been thoroughly discussed by numerous authors.[15, 16, 25, 26, 27, 28, 29] This author feels that to date Harvold's investigations[19, 20] on facial asymmetries and the mid-sagittal plane are the most significant to appear in the literature. However, several models of cephalostats employ nasion rests which produce shadows in the area of crista galli on the P-A cephalogram. For this reason it was found to be difficult to locate accurately Harvold's "X" registration point, at the root of crista galli, where it joins the cribriform plate of the ethmoid bone. This problem is well illustrated in Figure 1. As mentioned previously, Harvold[19] found that the right and left zygomatico-frontal sutures were very symmetrically placed relative to point "X". Because point "X" cannot be viewed consistently, it is

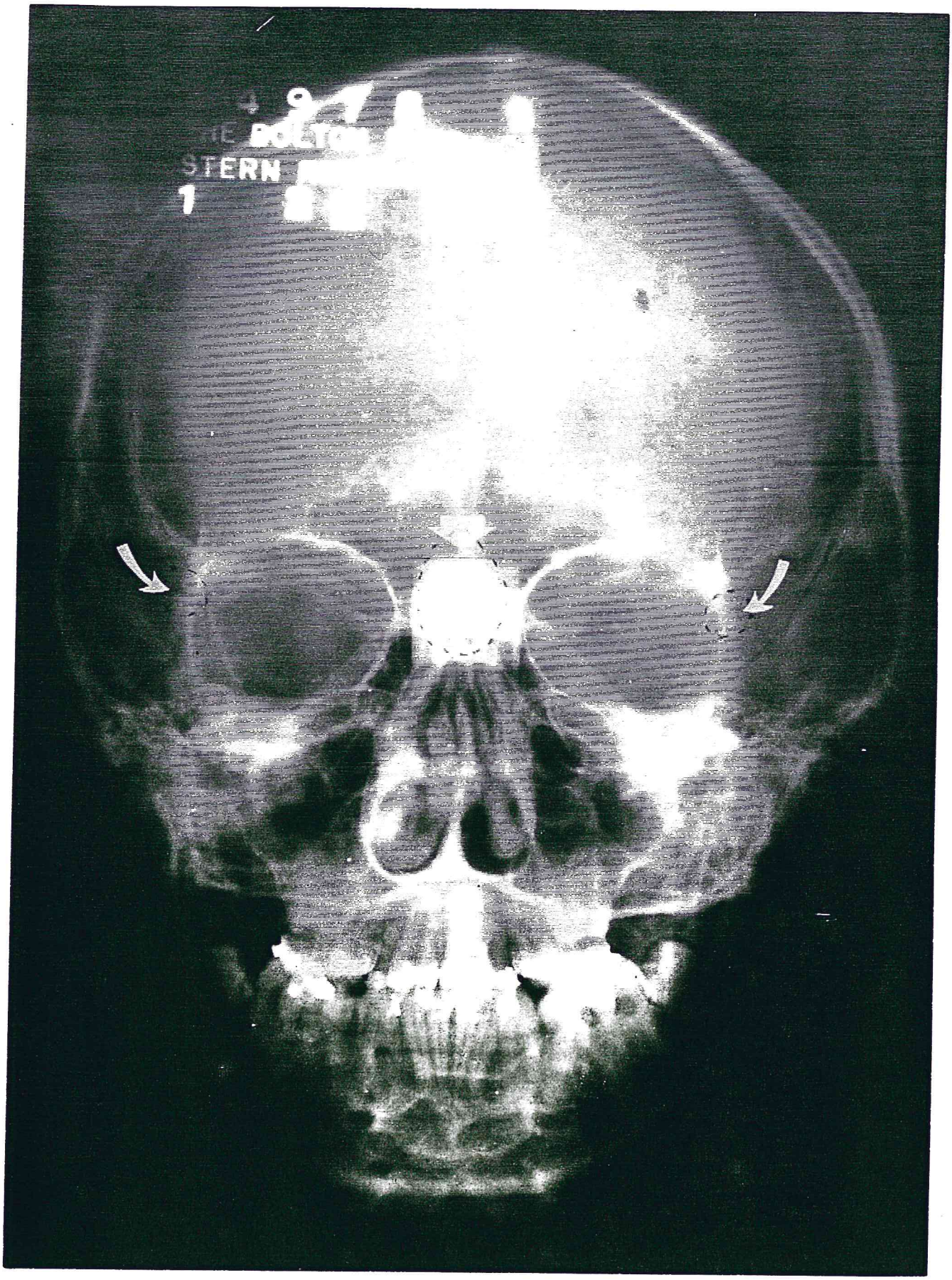

Fig. 1--P-A cephalogram showing area blocked out by the nasion rest and ease with which zygomatico-frontal sutures can be located.

my intention to bisect the width measurement as an alternate registration point for the mid-sagittal plane line. Since the lateralmost shadow of the zygomatico-frontal suture is quite easily established with the aid of a transparent millimeter grid, bisection of the total width can easily be accomplished. Therefore, if Harvold's contention that the right and left zygomatico-frontal sutures are very symmetrically placed relative to point "X" the results obtained from the W.R.U. modified technique should coincide closely with results obtained from the Harvold technique.

Keeping in mind Salzmann's admonition[30], "cephalometrics is a means of obtaining information; it is not an end in itself," the following investigation was undertaken.

METHODS OF PROCEDURE AND MATERIALS

Using two different positioning methods, postero-anterior cephalograms were made of 20 adult skulls with full complements of teeth and various types of occlusions. These skulls were obtained from the Department of Anatomy of the School of Medicine, Western Reserve University, and there was no regard to age, sex or size of these specimens. Kodak no screen film was used and the exposure times were determined according to the size and weight of the individual skull.

Positioning Procedure

METHOD I - The 20 skulls were first positioned in the Broadbent-Bolton cephalometer with Frankfort plane parallel to the floor. These skulls were suspended in a fixed position by means of the ear rods and the nasion rest. (Figures 2 and 3)

After a minimum period of 24 hours a random sample of 10 of these 20 skulls were repositioned in the same manner and P-A cephalograms obtained to determine the magnitude of the positioning error. The results of these measurements are recorded in Table 1.

METHOD II - The same 20 skulls were again positioned in the Broadbent-Bolton cephalometer with Frankfort Plane parallel to the floor; however, the nasion rest was omitted in suspending the skulls. Instead, an adjustable platform was attached below the cassette holder which made possible a method of suspending the skulls in a fixed position without the aid of a nasion rest. (Figures 4 and 5)

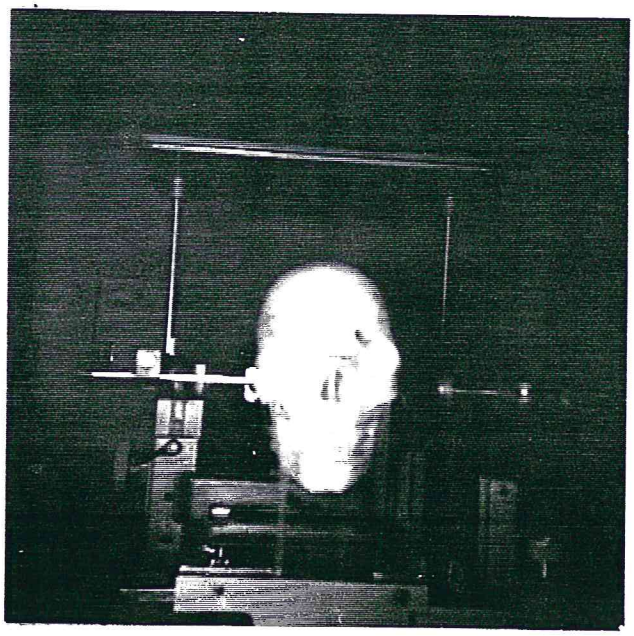

Fig. 2--Front view of skull positioned in the Broadbent-Bolton cephalometer by Method I.

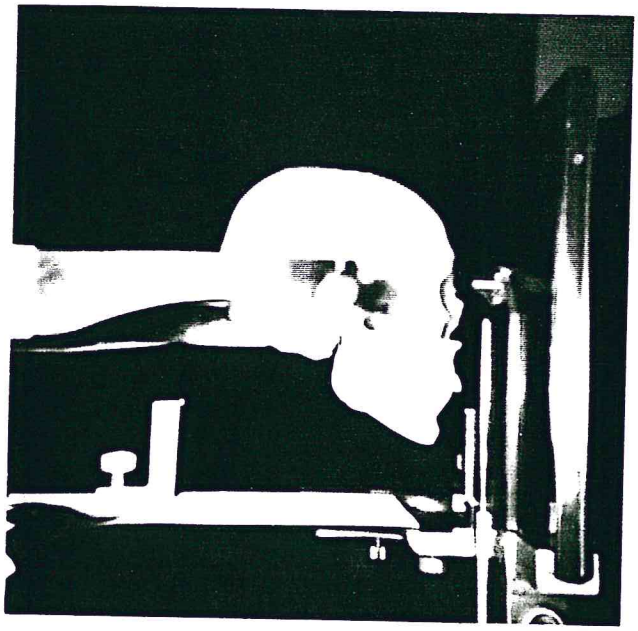

Fig. 3--Lateral view of skull positioned in the Broadbent-Bolton cephalometer by Method I.

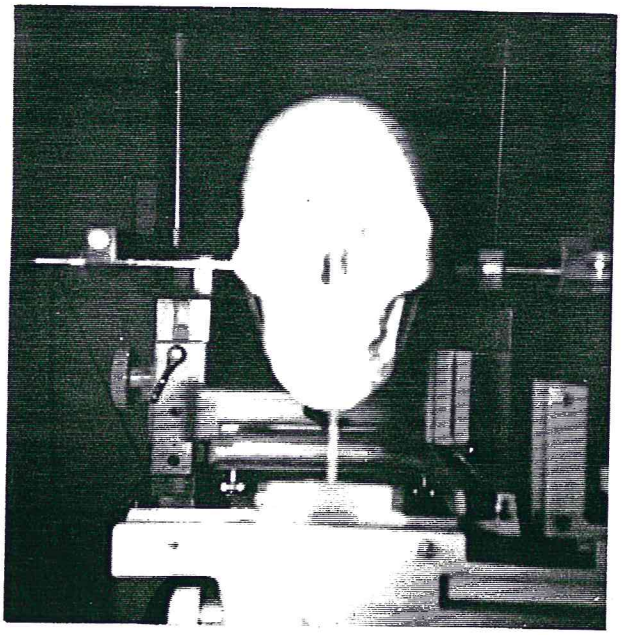

Fig. 4--Front view of skull positioned in the Broadbent-Bolton cephalometer by Method II.

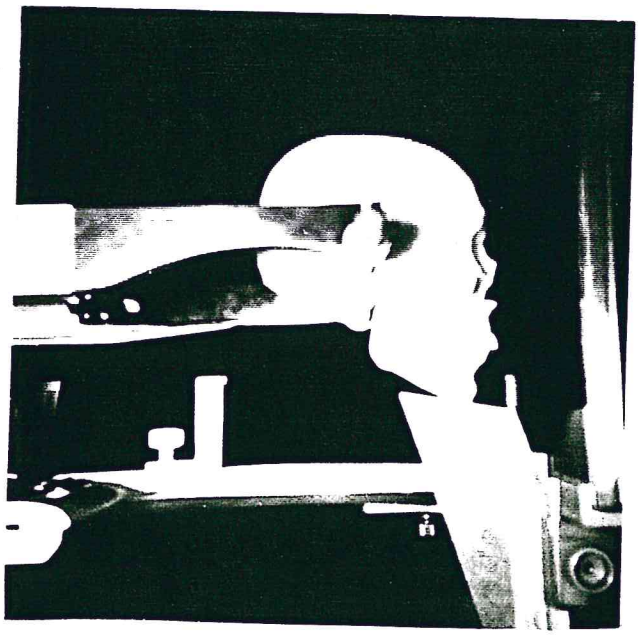

Fig. 5--Lateral view of skull positioned in the Broadbent-Bolton cephalometer by Method II.

After a minimum period of 24 hours a random sample of 10 of these 20 skulls which were positioned by Method II were again suspended in this manner and P-A cephalograms obtained to determine the magnitude of the positioning error. The results of these measurements are recorded in Table 2.

Tracing Procedure

METHOD I - Each P-A cephalogram of the 20 skulls positioned by Method I was placed on the illuminator and the following craniofacial landmarks were marked on the X-ray film with a fine wax pencil: (Figure 6)

1) The right and left zygomatico-frontal sutures.
2) The lateral aspect of the right and left zygoma.
3) The buccal contour of the right and left maxillary first molars.
4) The buccal contour of the right and left mandibular first molars.
5) The lateral contours of the ramus. (gonion)

METHOD II - Each P-A cephalogram of the 20 skulls positioned by Method II was placed on the illuminator and the following craniofacial landmarks were marked on the X-ray film with a fine wax pencil: (Figure 7)

1) The right and left zygomatico-frontal sutures.
2) Point X - the registration point of the center of the base of crista galli where it joins the cribriform plate of the ethmoid bone.
3) The lateral aspect of the right and left zygoma.
4) The buccal contour of the right and left maxillary first molars.

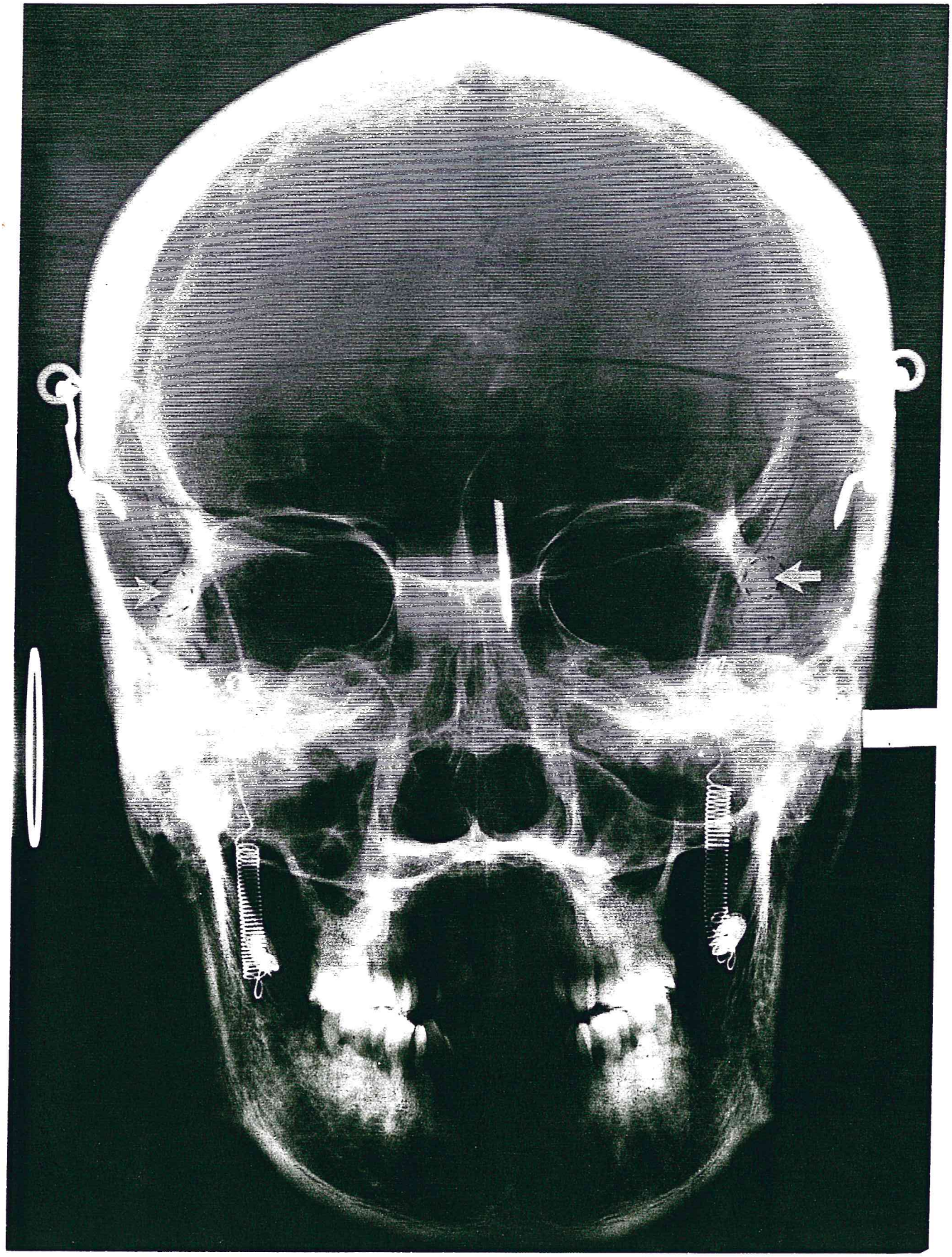

Fig. 6--P-A cephalogram of skull positioned by Method I.

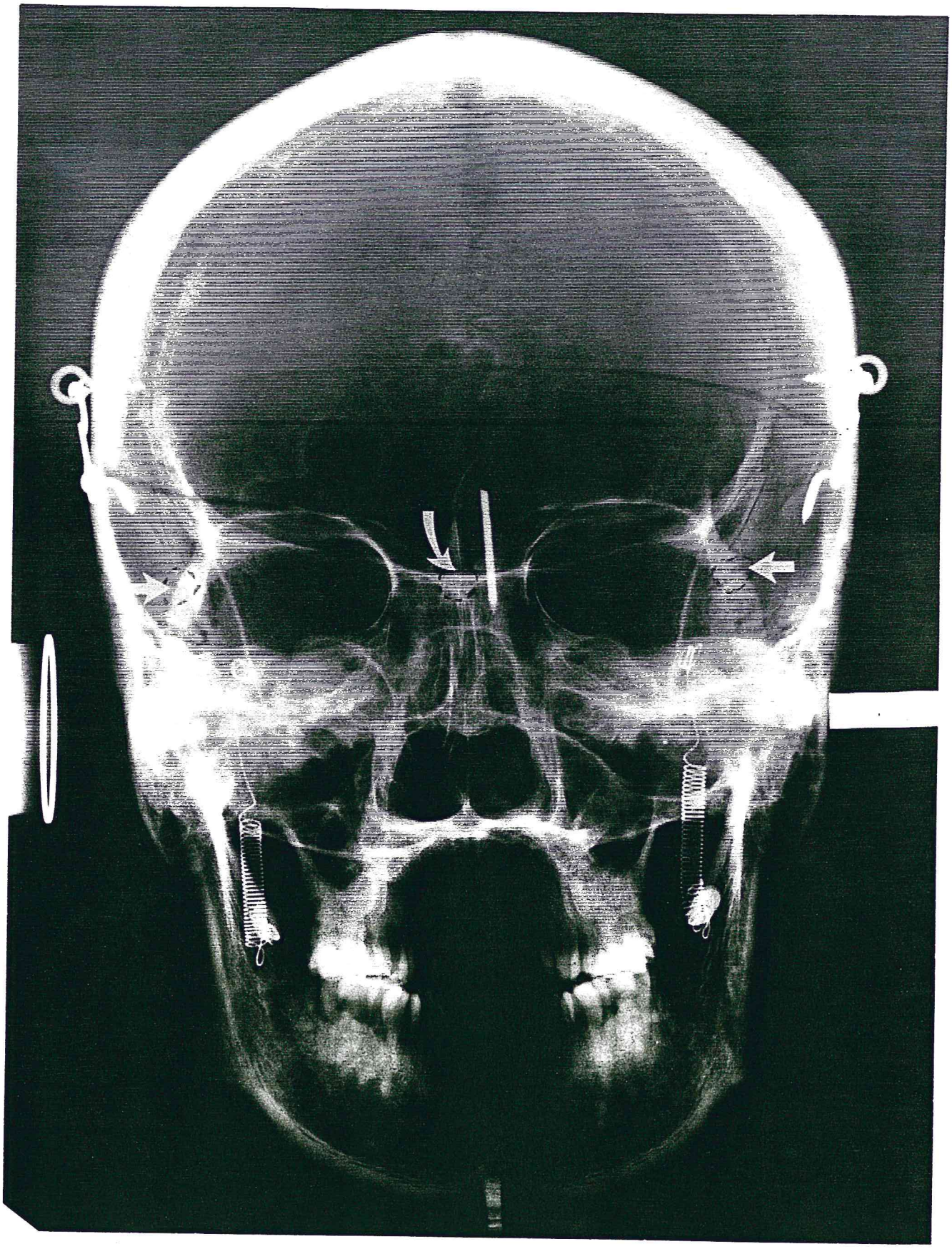

Fig. 7--P-A cephalogram of skull positioned by Method II.

5) The buccal contour of the right and left mandibular first molars.

6) The lateral contours of the ramus. (gonion)

Measuring Procedure

Harvold Method (Method II)

A. The transparent millimeter grid was placed on each of 20 marked P-A cephalograms which were positioned by Method II and the horizontal line "A" oriented so that it passed through the most lateral aspects of the right and left zygomatico-frontal sutures.

B. The vertical mid-sagittal plane line "B" was registered on the center of the root of crista galli where it joins the cribriform plate of the ethmoid bone. (Figure 8)

C. When orientation and registration were correct, the millimeter grid was taped to the P-A film.

D. The measurements listed below were noted from the grid and recorded to the nearest 0.5mm. Unless otherwise noted, all measurements are the lateral-most aspect of the structures being measured.

Zy. Fr. Su.
Zygoma
Mx. 6's
Md. 6's
Md. body W

The measurements obtained using the Harvold technique are presented in Table 3.

The wax markings of the craniofacial landmarks were removed with acetone from the X-ray films of Method II. After a minimum period of 24 hours a random sample of 10 of the original 20 cephalograms whose skulls were positioned by Method II were remarked and remeasured to determine the magnitude of the methodological error involved in the measurement following relocation of the craniofacial landmarks.

The results of the measurements are recorded in Table 4.

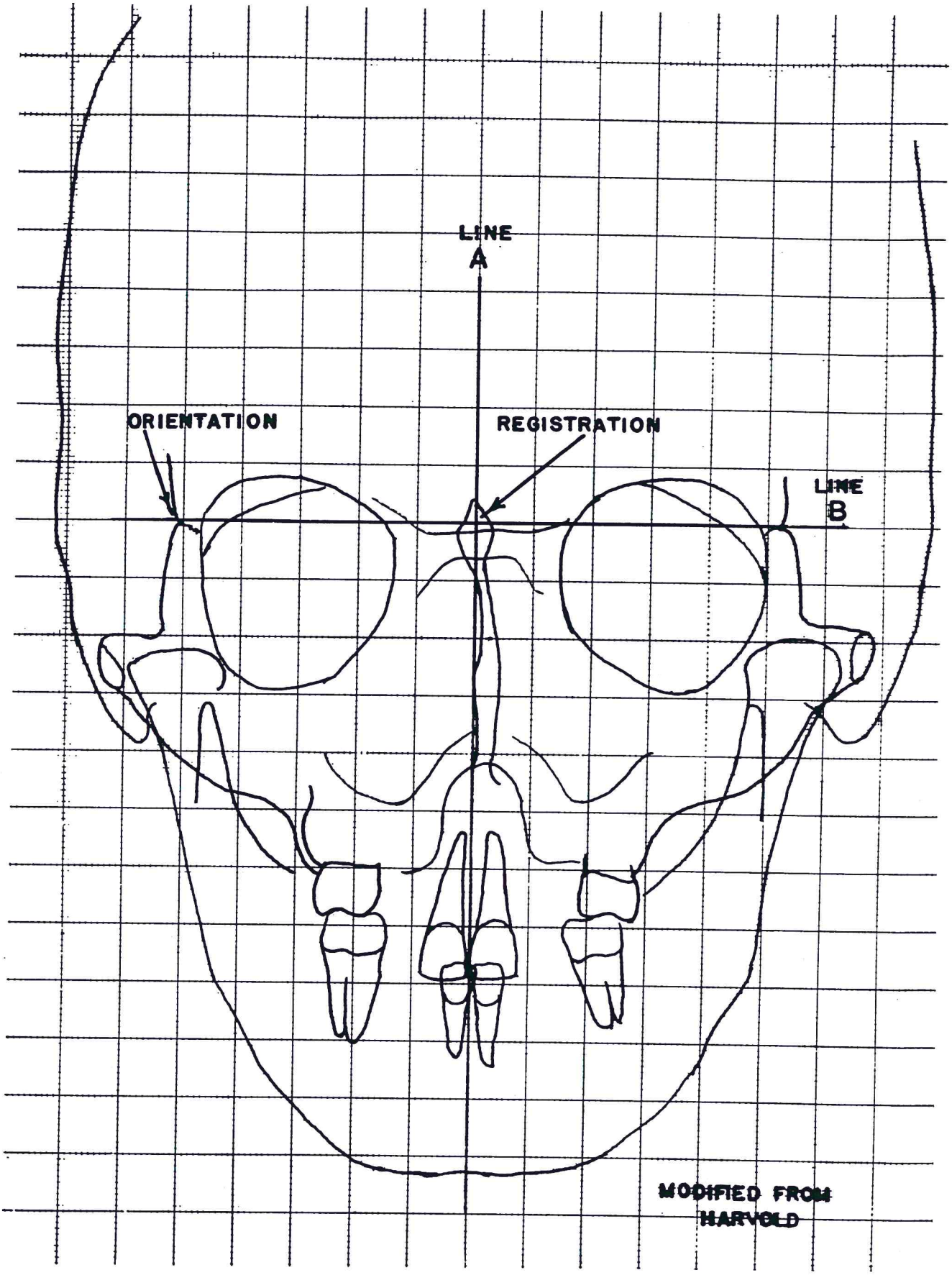

Fig. 8--Diagram showing outline of skull, grid and method of orientation for Harvold technique.

W.R.U. Modified Method (Method I)

The series of measurements was repeated this time using the 20 marked cephalograms obtained by positioning Method I and registering the midsagittal plane line "B" midway between the lateral-most aspect of the right and left zygomatico-frontal sutures. The measurements obtained using the W.R.U. Modified Technique are presented in Table 5.

The wax markings of the craniofacial landmarks were removed with acetone from the X-ray films of Method I. After a minimum period of 24 hours a random sample of 10 of the original 20 cephalograms whose skulls were positioned by Method I were remarked and remeasured to determine the magnitude of the methodological error involved in the measurement following relocation of the craniofacial landmarks.

The results of these measurements are recorded in Table 6.

STATISTICAL METHODS AND DATA

Since the Harvold P-A cephalograms used in this study were obtained with the skull in a vertical position rather than a horizontal position as originally done by Harvold[20], it was necessary to test the reproducibility of this variation in positioning. To test the differences between the Harvold left and right zygomatico-frontal sutures the right zygomatico-frontal suture measurement was subtracted from the left zygomatico-frontal suture measurement and the mean and standard deviation for this distribution determined. A one tailed 't' test was performed on the distribution of the differences. The statistical data for this test is presented in Table 7.

An analysis of variance was then performed on each of the ten sets of data, right zygomatico-frontal suture, left zygomatico-frontal suture, right zygoma, left zygoma, right maxillary first molar, left maxillary first molar, right mandibular first molar, left mandibular first molar, right gonion and left gonion, to determine if there was a significant difference between the results obtained using the Harvold method and the W.R.U. method. The variables in each analysis were M, the two methods, and N, the 20 skulls measured for each characteristic. The M and N variables were crossed with M a finite variable and N an infinite variable. The variance for the M effect was F tested against the variance of the MN effect to determine significance. This was first done with the α error set at the five per cent level. When a significant effect was found it

was retested with the error set at the one per cent level to see if the effect still proved to be significant. The results of these tests are presented in Tables 8, 9, 10, 11 and 12.

Analyses were next performed to determine the magnitude of the error. The first set of determinations was made on the results obtained when the skulls were repositioned and remeasured. The variables were R, the two measurements and N, a random sample of 10 of the original 20 skulls remeasured within each method. Both R and N were crossed with R infinite and N infinite. R and N were tested against RN and a variance for the error obtained after non-significant effects had been pooled. The statistical results of the error study for repositioning within each method are presented in Tables 13, 14, 15, 16, 17, 18, 19, 20, 21 and 22.

A similar set of analyses were performed to determine the magnitude of the error when the craniofacial landmarks were relocated and remeasured without repositioning of the skulls. A random sample of 10 of the original 20 skulls was used. The procedure was otherwise the same as that used in determining the repositioning error. The statistical results of the error study for the measurements following relocation of the craniofacial landmarks within each method are presented in Tables 23, 24, 25, 26, 27, 28, 29, 30, 31 and 32.

Tests were then made for the homogeneity of the error variances. The repositioning and landmark errors were first tested internally. The right zygomatico-frontal suture and left zygomatico-frontal suture within each method were tested using the Cochran test. A similar set of analyses were performed on the remaining measurements

and all results recorded in Tables 33, 34, 35 and 36. Where the errors were homogeneous the error between methods was tested for homogeneity. Thus the Harvold zygoma error was tested against the W.R.U. zygoma error. The statistical results of these tests are presented in Tables 37 and 38.

The repositioning error terms and landmark error terms were now tested for internal consistency. That is, for the repositioning errors the zygomatico-frontal suture, zygoma, etc., were Cochran tested for homogeneity. These statistical tests are presented in Tables 39 and 40.

Finally, the repositioning error was tested against the landmark relocation error and recorded in Table 41.

FINDINGS AND DISCUSSION

In this investigation a W.R.U. technique was being compared to the Harvold technique of establishing a mid-sagittal reference base. However, the postero-anterior cephalograms used to simulate the Harvold technique were obtained with the skull in a vertical rather than horizontal position. Thus, it was necessary to evaluate the simulated Harvold technique to which the W.R.U. technique was being compared. Harvold's results[19] indicated that in 90 per cent of cases his median plane divided the distance between the right and left zygomatic bones into two parts that differed by less than 3mm. As shown in Table 7 a one tailed 't' test was performed on the distribution of the differences of the Harvold left and right zygomatico-frontal suture measurements used in this study. The results showed that in the simulated Harvold technique, the median plane, in 90 per cent of cases divided the distance between the right and left zygomatic bones into two parts that differed by 2.70mm or less. This test demonstrated the close reproducibility of results obtained between the original Harvold technique and the Harvold technique used for comparison in this investigation.

Since one of the purposes of this study was to compare measurements of facial and dental asymmetries obtained by the Harvold technique with those derived from the W.R.U. technique an analysis of variance was performed on each of ten sets of measurements. These

statistical tests (Tables 8, 9, 10, 11 and 12) were to determine if there was a significant difference between the results obtained using the Harvold method and the W.R.U. method. In testing the M effect, the difference between methods, it was found to be significant at the five per cent level for the left zygomatico-frontal suture (Table 8) and significant at both the five per cent and one per cent levels for the right and left zygomas (Table 9). In all other cases the difference between methods was found to be not significant (Tables 10, 11 and 12). For the left zygomatico-frontal suture the W.R.U. method gave a mean difference of 0.43mm higher than that given by the Harvold method (Table 8). For both the right zygoma and left zygoma the W.R.U. method gave a mean difference of 0.65mm higher than that given by the Harvold method (Table 9). It was evident from the statistical analyses that the W.R.U. method showed a high degree of reproducibility of results when compared to the Harvold method. Since the results obtained from the W.R.U. modified technique coincided closely with the results obtained from the Harvold technique, it was also possible to support Harvold's contention[20] that the right and left zygomatico-frontal sutures are very symmetrically placed relative to point "X". Therefore, the W.R.U. method can be considered a reliable alternate procedure for the Harvold method in the establishment of a mid-sagittal reference base.

The experimental data were examined statistically to determine the methodological errors associated with the repositioning of the skulls and relocation of the craniofacial landmarks. In the error studies only one significant difference was found in the repositioning means (Tables 13, 14, 15, 16, 17, 18, 19, 20, 21 and 22). This was for the

Harvold left gonion (Table 17). The first position gave a mean difference of 0.45mm higher than the second position. This was significant at both the five per cent and one per cent levels. Why the first reading was higher than the second reading in this particular measurement cannot be explained.

In testing the homogeneity of the error variances for repositioning, all the zygomatico-frontal sutures, zygomas, maxillary first molars, mandibular first molars and gonions were found to be homogeneous for both the Harvold and W.R.U. methods (Tables 33 and 34). Thus there was no significant difference in the error variances for repositioning when left craniofacial measurements were tested against right craniofacial measurements within methods. The pooled error variances were then Cochran tested between methods. The only difference found was for the zygomatico-frontal suture (Table 37). In this case the variance for the Harvold method was .0995 and the variance for the W.R.U. method was .025. Further testing between zygomas, maxillary first molars, mandibular first molars and gonions produced the following two populations of variances (Table 39):

1. W.R.U. Zygomatico-frontal suture $\sigma_{RN}^2 = .025$ 20 D.F.
2. Harvold zygomatico-frontal suture, zygomas, Maxillary first molars, mandibular first molars and gonions $\sigma_{RN}^2 = .1928$ 180 D.F.

The landmark errors were then studied within methods (Tables 23, 24, 25, 26, 27, 28, 29, 30, 31 and 32). No difference was found between zygomatico-frontal sutures, zygomas, maxillary first molars, mandibular first molars and gonions (Tables 35 and 36). Across methods a significant difference was found only between the Harvold zygoma and

the W.R.U. zygoma (Table 38). For the Harvold zygoma the variance was .012 and for the W.R.U. zygoma the variance was .112. These pooled and unpooled variances were checked across zygomatico-frontal sutures, zygomas, maxillary first molars, mandibular first molars and gonions and produced the following three populations (Table 40):

1.	Zygomatico-frontal sutures	$\sigma_{RN}^2 = 0.0$	40 D.F.
2.	Harvold zygoma	$\sigma_{RN}^2 = .012$	20 D.F.
3.	W.R.U. zygoma, maxillary first molars, mandibular first molars and gonions	$\sigma_{RN}^2 = .1096$	140 D.F.

Finally the major pooled variances for the repositioning error and landmark error were Cochran tested (Table 41). A significant difference between these errors was found.

Since the landmark error is included in the repositioning error or total error shown in Table 39 it was necessary to subtract the landmark error from this total error in order to arrive at the true repositioning error. This was performed in Table 42 and the landmark error was shown to produce 56.8 per cent of the total variance.

SUMMARY AND CONCLUSIONS

This investigation was conducted to compare measurements of facial and dental asymmetries obtained by the Harvold method with those derived from a modified procedure and to develop a modification of Harvold's technique for establishing a mid-sagittal reference base.

Using two different positioning methods, 40 postero-anterior cephalograms were made of 20 adult skulls with full complements of teeth and various types of occlusions. The first positioning method was with a nasion rest in place and the second positioning method made use of an adjustable platform under the mandible for support so that the nasion rest could be eliminated. Error studies were conducted on both methods to determine the magnitude of the repositioning error.

Identical bilateral craniofacial landmarks were measured by use of a millimeter grid on the obtained postero-anterior cephalograms. The W.R.U. technique of measurement was used on the 20 cephalograms obtained by the first positioning method. Harvold's technique of measurement was used on the 20 cephalograms obtained by the second positioning method. Error studies were conducted on both techniques to determine the magnitude of the error associated with the relocation of craniofacial landmarks.

The experimental data of this study were subjected to statistical analysis and the following conclusions were formed:

1. The simulated Harvold median plane in 90 per cent of cases divided the distance between the right and left zygomatic bones into two parts that differed by 2.70mm or less. Therefore, the simulated Harvold technique used for comparison in this investigation demonstrated a close reproducibility of results when compared to the original Harvold technique.
2. The W.R.U. method produced a left zygomatico-frontal suture reading that was on the average 0.43mm higher than that obtained using the Harvold method. This difference in methods was significant at the five per cent level only.
3. The W.R.U. method produced a zygoma reading that was on the average 0.65mm higher than that obtained using the Harvold method. This difference in methods was significant at both the five per cent and one per cent levels.
4. In all other measurements the W.R.U. and Harvold methods produced readings that were not significantly different.
5. For both repositioning and landmark errors all zygomatico-frontal sutures, zygomas, maxillary first molars, mandibular first molars and gonions gave the same error within methods.
6. For the repositioning error (a) the W.R.U. zygomatico-frontal suture and (b) the Harvold zygomatico-frontal suture, zygomas, maxillary first molars, mandibular first molars and gonions constituted two separate populations.

7. For the landmark error the (a) zygomatico-frontal sutures, (b) Harvold zygoma and (c) W.R.U. zygoma, maxillary first molars, mandibular first molars and gonions each constituted a separate population.
8. There was a significant difference between landmark error and the repositioning error in all cases.

From the preceeding discussion and conclusions it is apparent first, that since all measurements were to the nearest 0.5mm the magnitude of the methodological error was small enough so that the procedures used to obtain the experimental data could be repeated with a high degree of accuracy. Second, the results indicated that the W.R.U. method was a reliable alternate procedure for the Harvold method in the establishment of a median plane. Finally, the W.R.U. method, which does not necessitate the location of Harvold's "X" point, provides the clinician with means of easily determining a mid-sagittal reference base from standard postero-anterior cephalograms.

APPENDIX

TABLE I

ERROR STUDY DATA FOR REPOSITIONING SKULLS IN THE CEPHALOMETER USING METHOD I

Skull Numbers	367	49	583	50	571	140	155	566	576	344
R. Zy. Fr. Su.	50.0	50.5	49.5	50.5	51.5	48.5	51.0	52.0	52.5	54.0
L. Zy. Fr. Su.	50.0	50.5	49.5	50.5	51.5	48.5	51.0	52.0	52.5	54.0
R. Zygoma	61.0	63.5	63.0	68.5	64.5	59.5	64.0	67.5	65.0	70.0
L. Zygoma	61.0	62.0	61.0	64.0	61.0	60.0	62.0	63.5	66.0	69.0
R. Mx. 6	30.5	29.5	30.0	34.0	32.0	30.0	29.5	29.0	34.0	30.5
L. Mx. 6	31.0	29.0	28.5	27.5	28.0	27.0	25.5	28.0	30.0	27.0
R. Md. 6	29.0	27.5	29.5	33.5	30.0	28.0	30.0	27.0	31.5	27.0
L. Md. 6	28.0	29.0	25.0	25.0	25.0	24.0	25.5	27.5	26.5	25.5
R. gonion	44.0	45.5	54.0	54.5	55.5	43.0	53.5	49.0	53.5	51.0
L. gonion	45.0	50.5	47.0	45.5	49.0	41.5	48.0	50.0	53.5	48.0

All measurements are in millimeters

TABLE 2

ERROR STUDY DATA FOR REPOSITIONING SKULLS
IN THE CEPHALOMETER USING METHOD II

Skull Numbers	367	49	583	50	571	140	155	566	576	344
R. Zy. Fr. Su.	48.5	50.5	49.0	49.5	50.5	49.5	52.0	51.5	52.0	53.0
L. Zy. Fr. Su.	49.0	50.5	49.5	49.5	50.5	49.0	48.5	51.5	52.0	53.0
R. Zygoma	60.0	63.0	62.5	67.5	64.0	59.0	65.0	66.0	64.0	68.0
L. Zygoma	60.0	61.5	60.5	63.0	60.5	59.5	59.5	63.0	65.5	68.5
R. Mx. 6	31.0	30.0	29.5	34.5	31.5	30.0	31.0	28.0	32.5	29.0
L. Mx. 6	30.5	29.0	29.0	26.0	27.5	28.0	23.5	29.0	30.5	27.5
R. Md. 6	28.5	27.5	29.0	34.0	30.0	28.0	31.5	27.0	31.0	26.5
L. Md. 6	28.0	29.0	25.5	24.0	24.5	24.0	23.0	27.5	27.5	25.0
R. gonion	43.5	47.0	52.5	54.5	55.0	43.5	55.0	47.5	52.0	49.5
L. gonion	45.0	48.5	47.5	44.5	49.5	41.0	46.0	49.0	53.0	49.5

All measurements are in millimeters

TABLE 3

MEASUREMENTS OBTAINED USING THE HARVOLD TECHNIQUE (METHOD II)

kull Numbers	229	154	255	50	550	130	49	566	367	361	576	344	155	340	583	140	571	135	563	146
. Zy. Fr. Su.	50.5	52.5	51.5	49.5	48.0	51.5	50.5	51.5	49.5	51.0	52.5	53.0	52.0	49.0	49.0	49.5	50.5	50.0	52.0	48.5
. Zy. Fr. Su.	51.5	51.0	54.0	49.5	46.5	52.5	50.5	51.5	48.5	51.0	51.5	54.0	48.5	51.0	49.5	48.5	51.5	49.0	51.0	49.0
. Zygoma	64.5	62.0	67.0	67.5	63.5	67.0	63.0	66.0	60.0	59.5	65.0	68.0	64.5	59.5	62.0	59.0	63.5	61.5	67.0	62.5
. Zygoma	61.0	62.0	67.0	63.0	61.5	62.0	61.5	63.0	60.0	61.0	65.0	69.0	60.0	60.0	61.5	59.5	61.0	60.0	61.0	62.0
. Mx. 6	33.5	31.0	30.0	34.5	30.5	31.5	29.5	28.0	30.0	27.0	33.0	29.0	31.0	28.0	29.5	30.5	31.0	29.0	31.5	26.0
. Mx. 6	32.0	29.0	31.0	26.0	27.5	28.0	29.0	29.0	31.5	29.0	30.0	27.5	24.5	29.5	29.0	27.0	28.0	28.0	31.0	27.5
Md. 6	29.0	31.0	29.0	33.5	28.5	29.5	27.0	26.5	28.0	26.0	32.0	27.0	31.5	27.0	29.0	28.0	29.5	26.0	29.0	25.0
Md. 6	28.0	28.0	28.0	24.0	25.5	25.0	29.0	28.0	29.0	28.0	26.0	25.0	24.0	28.0	25.5	25.0	25.0	26.0	31.0	25.0
gonion	49.5	53.0	51.5	54.5	43.0	50.0	46.5	48.0	42.5	44.5	53.0	48.5	54.0	44.5	52.5	43.5	54.0	45.0	49.5	48.0
gonion	50.5	52.0	51.0	44.5	43.0	40.5	48.5	49.5	46.0	45.0	53.0	50.0	47.0	46.0	48.5	41.0	50.0	42.5	48.5	46.5

All measurements are in millimeters

TABLE 4

ERROR STUDY DATA FOR MEASUREMENTS FOLLOWING RELOCATION OF THE CRANIOFACIAL LANDMARKS USING METHOD II

Skull Numbers	229	255	130	154	49	566	361	155	583	140
R. Zy. Fr. Su.	50.5	51.5	51.5	52.5	50.5	51.5	51.0	52.0	49.0	49.5
L. Zy. Fr. Su.	51.5	54.0	52.5	51.0	50.5	51.5	51.0	48.0	49.5	48.5
R. Zygoma	65.0	67.0	67.0	62.0	63.0	66.0	59.5	64.5	62.0	59.0
L. Zygoma	61.0	66.5	62.0	62.0	61.5	63.0	61.0	60.0	61.5	59.5
R. Mx. 6	34.0	30.5	31.0	31.5	29.5	28.0	27.5	31.0	29.5	30.0
L. Mx. 6	31.0	30.5	28.5	28.5	29.0	28.5	29.0	24.0	29.0	27.0
R. Md. 6	29.5	29.0	29.0	31.0	27.0	26.5	26.5	31.0	29.0	28.0
L. Md. 6	27.5	28.0	25.5	28.0	29.0	28.0	28.5	23.5	25.0	25.0
R. gonion	50.0	51.5	49.5	53.5	46.5	48.0	44.0	54.0	52.0	44.0
L. gonion	50.5	51.0	41.0	51.5	48.5	49.5	45.5	47.0	48.5	40.0

All measurements are in millimeters

TABLE 5

MEASUREMENTS OBTAINED USING THE W. R. U. TECHNIQUE (METHOD I)

Skull Numbers	229	154	255	50	550	130	49	566	367	361	576	344	155	340	583	140	571	135	563	146
Zy. Fr. Su.	51.0	52.0	53.5	50.5	47.5	52.5	50.5	51.5	50.0	51.0	52.5	54.0	51.0	50.5	49.5	49.0	51.5	49.5	52.0	49.0
Zy. Fr. Su.	51.0	52.0	53.5	50.5	47.5	52.5	50.5	51.5	50.0	51.0	52.5	54.0	51.0	50.5	49.5	49.0	51.5	49.5	52.0	49.0
Zygoma	65.5	62.0	68.0	69.0	63.0	68.0	63.5	66.5	61.0	60.5	64.5	69.5	65.0	61.0	63.0	59.5	64.0	61.5	67.0	63.5
Zygoma	62.0	63.0	66.5	63.5	63.5	62.0	62.0	64.0	61.0	61.5	66.5	69.5	62.0	60.0	61.5	60.0	61.0	60.0	62.0	63.0
Mx. 6	34.0	31.0	31.5	36.0	29.5	31.0	29.0	29.0	30.5	28.0	33.0	30.0	29.5	29.0	30.5	30.5	31.5	28.5	31.0	27.0
Mx. 6	31.0	30.0	30.5	26.0	29.0	29.0	30.0	28.0	31.5	29.0	31.0	26.5	26.0	29.0	28.0	27.5	28.5	29.0	32.0	27.0
Md. 6	31.0	31.0	29.0	34.5	27.5	29.0	26.5	28.0	28.5	27.0	31.5	28.0	30.0	28.0	30.0	28.0	30.0	25.5	30.0	25.0
Md. 6	26.0	29.0	28.0	24.0	26.5	26.0	30.0	27.0	28.5	28.5	27.0	24.5	25.0	27.0	25.0	25.0	25.0	27.0	32.5	24.5
gonion	53.0	53.0	52.0	55.0	42.5	50.0	46.5	49.0	44.0	45.0	52.5	49.0	53.0	46.0	54.0	43.5	55.0	44.0	49.0	48.0
gonion	49.0	52.5	50.5	45.0	44.0	41.0	49.5	50.0	45.5	46.0	54.0	50.0	49.0	45.0	47.0	41.0	49.5	43.5	49.5	47.0

All measurements are in millimeters

TABLE 6

ERROR STUDY DATA FOR MEASUREMENTS FOLLOWING RELOCATION OF THE CRANIOFACIAL LANDMARKS USING METHOD I

Skull Numbers	229	255	130	154	49	566	361	155	583	140
R. Zy. Fr. Su.	51.0	53.5	52.5	52.0	50.5	51.5	51.0	51.0	49.5	49.0
L. Zy. Fr. Su.	51.0	53.5	52.5	52.0	50.5	51.5	51.0	51.0	49.5	49.0
R. Zygoma	66.5	69.0	68.0	62.0	63.5	67.0	60.5	64.0	63.0	59.5
L. Zygoma	61.0	66.0	62.0	63.0	62.0	64.0	61.0	62.0	61.5	60.0
R. Mx. 6	34.0	31.5	31.5	31.5	29.5	29.0	27.5	30.0	30.0	30.5
L. Mx. 6	31.0	30.5	28.5	29.5	29.5	28.5	30.0	26.0	28.5	27.0
R. Md. 6	31.0	29.0	29.5	30.5	26.5	27.0	26.0	29.5	29.5	28.5
L. Md. 6	26.0	28.0	25.5	29.0	30.0	28.0	29.5	25.0	25.5	25.0
R. gonion	52.5	52.0	50.5	53.0	47.0	50.0	44.0	53.0	53.5	44.0
L. gonion	49.0	50.5	40.0	52.5	49.0	49.0	46.5	48.5	47.5	40.0

All measurements are in millimeters

TABLE 7

TEST TO DETERMINE THE REPRODUCIBILITY OF RESULTS OBTAINED BY THE HARVOLD METHOD USED IN THIS INVESTIGATION (P-A CEPHALOGRAM WITH SKULL IN VERTICAL POSITION)

Distribution of Differences
Harvold Method

Skull Number	R.Zy.Fr.Su. - L.Zy.Fr.Su.	$(R.Zy.Fr.Su. - L.Zy.Fr.Su.)^2$
229	2.0mm	
154	-.5	
255	3.5	
50	1.0	
550	-.5	
130	2.0	
49	1.0	
566	1.0	
367	0.0	
361	1.0	
576	0.0	
344	2.0	
155	-2.5	
340	3.0	
583	1.5	
140	0.0	
571	2.0	
135	0.0	
563	0.0	
146	1.5	
	18.0mm	$52.50mm^2$

X_1 = Harvold L.Zy.Fr.Su.
X_2 = Harvold R.Zy.Fr.Su.

$D = X_1 - X_2$

$\bar{D} = \frac{\Sigma D}{N}$ $\quad N = 20$

$$\sigma_D = \sqrt{\frac{\Sigma D^2}{N} - \left(\frac{\Sigma D}{N^2}\right)^2} = \sqrt{1.815} = 1.35$$

$t_{90} = 1.33$ one tail 20 degrees of freedom

$\bar{D} = .90 \pm t\sigma_D = .90 \pm 1.80 = 2.70mm$ or less 90%

TABLE 8

ANALYSIS OF VARIANCE FOR THE MEASUREMENTS OF LEFT AND RIGHT ZYGOMATICO-FRONTAL SUTURES TO DETERMINE IF THERE IS A SIGNIFICANT DIFFERENCE BETWEEN METHODS I AND II

Left Zygomatico-frontal Suture

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
M	1.80	1	1.80	4.35	6.20
N	111.07	19	5.85		
MN	5.57	19	.29		
TOTAL	118.44	39			

The M effect is significant.
M_1 (Harvold) = 4.00mm
M_2 (W.R.U.) = 4.43mm
At 1% level $F_{.99}$ = 8.10 and the M effect is not significant.

Right Zygomatico-frontal Suture

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
M	2.12	1	2.12	4.35	3.62
N	165.74	19	8.72		
MN	11.13	19	.586		
TOTAL	178.99	39			

The M effect is not significant.

TABLE 9

ANALYSIS OF VARIANCE FOR THE MEASUREMENTS OF LEFT AND RIGHT ZYGOMAS TO DETERMINE IF THERE IS A SIGNIFICANT DIFFERENCE BETWEEN METHODS I AND II

Left Zygoma

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
M	4.22	1	4.22	4.35	17.73
N	220.12	19	11.59		
MN	4.53	19	.238		
TOTAL	228.87	39			

The M effect is significant at both the 5% and 1% levels.
M_1 = 3.05mm
M_2 = 3.70mm

Right Zygoma

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
M	4.23	1	4.23	4.35	22.87
N	321.65	19	16.93		
MN	3.52	19	.185		
TOTAL	329.40	39			

The M effect is significant at both the 5% and 1% levels.
M_1 = 4.63mm
M_2 = 5.28mm

S.V. = Source of Variation
S.S. = Sums of Squares
D.F. = Degrees of Freedom
M.S. = Mean Square
M = Two Methods
N = Skulls

TABLE 10

ANALYSIS OF VARIANCE FOR THE MEASUREMENTS OF LEFT AND RIGHT MAXILLARY FIRST MOLARS TO DETERMINE IF THERE IS A SIGNIFICANT DIFFERENCE BETWEEN METHODS I AND II

Left Maxillary First Molar

S.V.	S.S.	D.F.	M.S.	F.95	F
M	.27	1	.27	4.35	.67
N	118.24	19	6.22		
MN	7.60	19	.40		
TOTAL	126.11	39			

The M effect is not significant.

Right Maxillary First Molar

S.V.	S.S.	D.F.	M.S.	F.95	F
M	.90	1	.90	4.35	2.50
N	160.35	19	8.44		
MN	6.85	19	.36		
TOTAL	168.10	39			

The M effect is not significant.

TABLE 11

ANALYSIS OF VARIANCE FOR THE MEASUREMENTS OF LEFT AND RIGHT MANDIBULAR FIRST MOLARS TO DETERMINE IF THERE IS A SIGNIFICANT DIFFERENCE BETWEEN METHODS I AND II

Left Mandibular First Molar

S.V.	S.S.	D.F.	M.S.	F.95	F
M	.22	1	.22	4.35	.52
N	151.72	19	7.99		
MN	8.03	19	.42		
TOTAL	159.97	39			

The M effect is not significant.

Right Mandibular First Molar

S.V.	S.S.	D.F.	M.S.	F.95	F
M	.90	1	.90	4.35	2.25
N	177.00	19	9.31		
MN	7.60	19	.40		
TOTAL	185.50	39			

The M effect is not significant

S.V. = Source Variation
S.S. = Sums of Squares
D.F. = Degrees of Freedom
M.S. = Mean Square
M = Two Methods
N = Skulls

TABLE 12

ANALYSIS OF VARIANCE FOR THE MEASUREMENTS OF LEFT AND RIGHT GONIONS TO DETERMINE IF THERE IS A SIGNIFICANT DIFFERENCE BETWEEN METHODS I AND II

Left Gonion

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
M	.63	1	.63	4.35	1.47
N	475.65	19	25.03		
MN	8.12	19	.43		
TOTAL	484.40	39			

The M effect is not significant.

Right Gonion

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
M	1.80	1	1.80	4.35	3.21
N	615.37	19	32.39		
MN	10.57	19	.56		
TOTAL	627.74	39			

The M effect is not significant.

S.V. = Source of Variation
S.S. = Sums of Squares
D.F. = Degrees of Freedom
M.S. = Mean Square
M = Two Methods
N = Skulls

TABLE 13

ANALYSIS OF VARIANCE TO DETERMINE THE REPOSITIONING ERROR FOR THE RIGHT AND LEFT ZYGOMATICO-FRONTAL SUTURES USING THE HARVOLD METHOD

Right Zygomatico-frontal Suture

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.12	1	.12	5.12	2.18
N	37.52	9	4.17	3.02	65.60
RN	.50	9	.055		
TOTAL	38.14	19			

The R effect is not significant.

σ_{RN} = 2.49mm

Pooled mean square = .062mm^2

Left Zygomatico-frontal Suture

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.02	1	.02	5.12	N.S.
N	47.27	9	5.25	3.02	37.5
RN	1.35	9	.15		
TOTAL	48.64	19			

The R effect is not significant.

σ_{RN} = .370mm

Pooled mean square = .137mm^2

TABLE 14

ANALYSIS OF VARIANCE TO DETERMINE THE REPOSITIONING ERROR FOR THE RIGHT AND LEFT ZYGOMAS USING THE HARVOLD METHOD

Right Zygoma

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.02	1	.02	5.12	N.S.
N	155.94	9	17.32	3.02	173.2
RN	.98	9	.11		
TOTAL	156.94	19			

The R effect is not significant.

σ_{RN} = .316mm

Pooled mean square = .10mm^2

Left Zygoma

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.20	1	.20	5.12	2.22
N	151.25	9	16.81	3.02	16.81
RN	.80	9	.09		
TOTAL	152.25	19			

The R effect is not significant.

σ_{RN} = .316mm

Pooled mean square = .10mm^2

S.V. = Source of Variation
S.S. = Sums of Squares
D.F. = Degrees of Freedom
M.S. = Mean Square
R = Two measurements
N = Random sample of ten skulls

TABLE 15

ANALYSIS OF VARIANCE TO DETERMINE THE REPOSITIONING ERROR FOR THE RIGHT AND LEFT MAXILLARY FIRST MOLARS USING THE HARVOLD METHOD

Right Maxillary First Molar

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.05	1	.05	5.12	N.S.
N	63.55	9	7.06	3.02	70.6
RN	.95	9	.106		
TOTAL	64.55	19			

The R effect is not significant.

σ_{RN} = .316mm

Pooled mean square = .10mm^2

Left Maxillary First Molar

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.05	1	.05	5.12	N.S.
N	75.05	9	8.34	3.02	47.7
RN	1.70	9	.188		
TOTAL	76.80	19			

The R effect is not significant.

σ_{RN} = .418mm

Pooled mean square = .175mm^2

TABLE 16

ANALYSIS OF VARIANCE TO DETERMINE THE REPOSITIONING ERROR FOR THE RIGHT AND LEFT MANDIBULAR FIRST MOLARS USING THE HARVOLD METHOD

Right Mandibular First Molar

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.05	1	.05	5.12	N.S.
N	99.50	9	11.06	3.02	88.48
RN	1.20	9	.13		
TOTAL	100.75	19			

The R effect is not significant.

σ_{RN} = .354mm

Pooled mean square = .125mm^2

Left Mandibular First Molar

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.32	1	.32	5.12	N.S.
N	68.27	9	7.58	3.02	30.0
RN	2.55	9	.27		
TOTAL	71.14	19			

The R effect is not significant.

σ_{RN} = .534mm

Pooled mean square = .287mm^2

S.V. = Source of Variation
S.S. = Sums of Squares
D.F. = Degrees of Freedom
M.S. = Mean Square
R = Two measurements
N = Random sample of ten skulls

TABLE 17

ANALYSIS OF VARIANCE TO DETERMINE THE REPOSITIONING ERROR FOR THE RIGHT AND LEFT GONIONS USING THE HARVOLD METHOD

Right Gonion

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.45	1	.45	5.12	1.76
N	361.80	9	40.20	3.02	46.20
RN	2.30	9	.256		
TOTAL	364.55	19			

The R effect is not significant.

σ_{RN} = .505mm

Pooled mean square = .275mm^2

Left Gonion

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	1.02	1	1.02	5.12	10.85
N	201.77	9	22.41	3.18	238.4
RN	.85	9	.094		
TOTAL	203.64	19			

The R effect is significant at the 5% level.

σ_{RN} = .307mm

$F_{.99}$ = 10.6 The R effect is significant at the 1% level.

TABLE 18

ANALYSIS OF VARIANCE TO DETERMINE THE REPOSITIONING ERROR FOR THE RIGHT AND LEFT ZYGOMATICO-FRONTAL SUTURES USING THE W.R.U. METHOD

Right Zygomatico-frontal Suture

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	0.0	1	0	5.12	N.S.
N	41.75	9	4.638	3.02	166.8
RN	.25	9	.0278		
TOTAL	42.00	19			

The R effect is not significant.

σ_{RN} = .167mm

Pooled mean square = .025mm^2

Left Zygomatico-frontal Suture

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	0.0	1	0	5.12	N.S.
N	41.75	9	4.638	3.02	166.8
RN	.25	9	.0278		
TOTAL	42.00	19			

The R effect is not significant.

σ_{RN} = .167mm

Pooled mean square = .025mm^2

S.V. = Source of Variation
S.S. = Sums of Squares
D.F. = Degrees of Freedom
M.S. = Mean Square
R = Two measurements
N = Random sample of ten skulls

TABLE 19

ANALYSIS OF VARIANCE TO DETERMINE THE REPOSITIONING ERROR FOR THE RIGHT AND LEFT ZYGOMAS USING THE W.R.U. METHOD

Right Zygoma

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	0.05	1	.05	5.12	.31
N	184.80	9	20.53	3.02	136.80
RN	1.45	9	.16		
TOTAL	186.30	19			

The R effect is not significant.

σ_{RN} = .387mm

Pooled mean square = .15mm^2

Left Zygoma

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	0.12	1	.12	5.12	2.16
N	145.62	9	16.18	3.02	260.90
RN	.50	9	.0555		
TOTAL	146.24	19			

The R effect is not significant.

σ_{RN} = .249mm

Pooled mean square = .062mm^2

TABLE 20

ANALYSIS OF VARIANCE TO DETERMINE THE REPOSITIONING ERROR FOR THE RIGHT AND LEFT MAXILLARY FIRST MOLARS USING THE W.R.U. METHOD

Right Maxillary First Molar

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.02	1	.02	5.12	N.S.
N	68.02	9	7.56	3.02	242.3
RN	3.10	9	.344		
TOTAL	71.14	19			

The R effect is not significant.

σ_{RN} = .557mm

Pooled mean square = .312mm^2

Left Maxillary First Molar

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.12	1	.12	5.12	N.S.
N	54.87	9	6.10	3.02	212.5
RN	2.75	9	.306		
TOTAL	57.74	19			

The R effect is not significant.

σ_{RN} = .536mm

Pooled mean square = .287mm^2

S.V. = Source of variation
S.S. = Sums of Squares
D.F. = Degrees of Freedom
M.S. = Mean Square
R = Two measurements
N = Random sample of ten skulls

TABLE 21

ANALYSIS OF VARIANCE TO DETERMINE THE REPOSITIONING ERROR FOR THE RIGHT AND LEFT MANDIBULAR FIRST MOLARS USING THE W.R.U. METHOD

Right Mandibular First Molar

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F.
R	.20	1	.20	5.12	N.S.
N	83.55	9	9.28	3.02	41.20
RN	2.05	9	.227		
TOTAL	85.80	19			

The R effect is not significant.

σ_{RN} = .474mm

Pooled mean square = .225mm^2

Left Mandibular First Molar

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F.
R	0.0	1	0.0	5.12	N.S.
N	54.80	9	6.09	3.02	21.90
RN	2.50	9	.278		
TOTAL	57.30	19			

The R effect is not significant.

σ_{RN} = .527mm

Pooled mean square = .250mm^2

TABLE 22

ANALYSIS OF VARIANCE TO DETERMINE THE REPOSITIONING ERROR FOR THE RIGHT AND LEFT GONIONS USING THE W.R.U. METHOD

Right Gonion

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F.
R	.20	1	.20	5.12	N.S.
N	367.25	9	40.80	3.02	116.60
RN	3.30	9	.366		
TOTAL	370.75	19			

The R effect is not significant.

σ_{RN} = .592mm

Pooled mean square = .350mm^2

Left Gonion

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F.
R	.32	1	.32	5.12	N.S.
N	211.02	9	23.45	3.02	65.10
RN	3.30	9	.366		
TOTAL	214.64	19			

The R effect is not significant.

σ_{RN} = .60mm

Pooled mean square = .360mm^2

S.V. = Source of Variation
S.S. = Sums of Squares
D.F. = Degrees of Freedom
M.S. = Mean Square
R = Two measurements
N = Random sample of ten skulls

TABLE 23

ANALYSIS OF VARIANCE TO DETERMINE THE LANDMARK ERROR FOR THE RIGHT AND LEFT ZYGOMATICO-FRONTAL SUTURES USING THE HARVOLD METHOD

NOTE: $\sigma_{RN}^2 = 0mm^2$

No error for the right and left zygomatico-frontal sutures.

TABLE 24

ANALYSIS OF VARIANCE TO DETERMINE THE LANDMARK ERROR FOR THE RIGHT AND LEFT ZYGOMAS USING THE HARVOLD METHOD

Right Zygoma

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.02	1	.02	5.12	N.S.
N	148.62	9	16.50	3.02	1375.0
RN	.10	9	.011		
TOTAL	148.74	19			

The R effect is not significant.

σ_{RN} = .11mm

Pooled mean square = .012mm^2

Left Zygoma

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.02	1	.02	5.12	N.S.
N	72.02	9	8.00	3.02	667.0
RN	.10	9	.011		
TOTAL	72.14	19			

The R effect is not significant.

σ_{RN} = .11mm

Pooled mean square = .012mm^2

TABLE 25

ANALYSIS OF VARIANCE TO DETERMINE THE LANDMARK ERROR FOR THE RIGHT AND LEFT MAXILLARY FIRST MOLARS USING THE HARVOLD METHOD

Right Maxillary First Molar

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.05	1	.05	5.12	N.S.
N	59.95	9	6.66	3.02	88.8
RN	.70	9	.078		
TOTAL	60.70	19			

The R effect is not significant.

σ_{RN} = .274mm

Pooled mean square = .075mm^2

Left Maxillary First Molar

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.32	1	.32	5.12	3.56
N	70.32	9	7.81	3.02	69.70
RN	.80	9	.089		
TOTAL	71.44	19			

The R effect is not significant.

σ_{RN} = .333mm

Pooled mean square = .112mm^2

S.V. = Source of Variation
S.S. = Sums of Squares
D.F. = Degrees of Freedom
M.S. = Mean Square
R = Two Measurements
N = Random sample of ten skulls

TABLE 26

ANALYSIS OF VARIANCE TO DETERMINE THE LANDMARK ERROR FOR THE RIGHT AND LEFT MANDIBULAR FIRST MOLARS USING THE HARVOLD METHOD

Right Mandibular First Molar

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	0.0	1	0.0	5.12	N.S.
N	53.55	9	5.95	3.02	107.0
RN	.50	9	.0556		
TOTAL	54.05	19			

The R effect is not significant.

σ_{RN} = .236mm

Pooled mean square = .056mm^2

Left Mandibular First Molar

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.02	1	.02	5.12	N.S.
N	59.02	9	6.56	3.02	105.8
RN	.60	9	.067		
TOTAL	59.64	19			

The R effect is not significant.

σ_{RN} = .249mm

Pooled mean square = .062mm^2

TABLE 27

ANALYSIS OF VARIANCE TO DETERMINE THE LANDMARK ERROR FOR THE RIGHT AND LEFT GONIONS USING THE HARVOLD METHOD

Right Gonion

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	0.0	1	0.0	5.12	N.S.
N	234.95	9	26.10	3.02	348.0
RN	.75	9	.075		
TOTAL	235.70	19			

The R effect is not significant.

σ_{RN} = .295mm

Pooled mean square = .075mm^2

Left Gonion

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.02	1	.02	5.12	N.S.
N	289.77	9	32.20	3.02	370.0
RN	.85	9	.094		
TOTAL	290.64	19			

The R effect is not significant.

σ_{RN} = .295mm

Pooled mean square = .087mm^2

S.V. = Source of Variation
S.S. = Sums of Squares
D.F. = Degrees of Freedom
M.S. = Mean Square
R = Two Measurements
N = Random sample of ten skulls

TABLE 28

ANALYSIS OF VARIANCE TO DETERMINE THE LANDMARK ERROR FOR THE RIGHT AND LEFT ZYGOMATICO-FRONTAL SUTURES USING THE W.R.U. METHOD

NOTE: $\sigma_{RN}^2 = 0mm^2$

No error for the right and left zygomatico-frontal sutures.

TABLE 29

ANALYSIS OF VARIANCE TO DETERMINE THE LANDMARK ERROR FOR THE RIGHT AND LEFT ZYGOMAS USING THE W.R.U. METHOD

Right Zygoma

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	0.12	1	0.12	5.12	N.S.
N	170.62	9	18.96	3.02	117.0
RN	1.50	9	.167		
TOTAL	172.24	19			

The R effect is not significant.

σ_{RN} = .402mm

Pooled mean square = .162mm^2

Left Zygoma

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	.12	1	0.12	5.12	2.18
N	55.02	9	6.11	3.02	98.50
RN	.50	9	.055		
TOTAL	55.64	19			

The R effect is not significant.

σ_{RN} = .249mm

Pooled mean square = .062mm^2

TABLE 30

ANALYSIS OF VARIANCE TO DETERMINE THE LANDMARK ERROR FOR THE RIGHT AND LEFT MAXILLARY FIRST MOLARS USING THE W.R.U. METHOD

Right Maxillary First Molar

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	0.05	1	0.05	5.12	N.S.
N	52.70	9	5.86	3.02	78.0
RN	.70	9	.078		
TOTAL	53.45	19			

The R effect is not significant.

σ_{RN} = .274mm

Pooled mean square = .075mm^2

Left Maxillary First Molar

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	0.0	1	0.0	5.12	N.S.
N	41.55	9	4.617	3.02	36.9
RN	1.25	9	.125		
TOTAL	42.80	19			

The R effect is not significant.

σ_{RN} = .354mm

Pooled mean square = .125mm^2

S.V. = Source of variation
S.S. = Sums of squares
D.F. = Degrees of Freedom
M.S. = Mean Square
R = Two measurements
N = Random sample of ten skulls

TABLE 31

ANALYSIS OF VARIANCE TO DETERMINE THE LANDMARK ERROR FOR THE RIGHT AND LEFT MANDIBULAR FIRST MOLARS USING THE W.R.U. METHOD

Right Mandibular First Molar

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	0.32	1	0.32	5.12	2.2
N	46.52	9	5.169	3.02	31.9
RN	1.30	9	.144		
TOTAL	48.14	19			

The R effect is not significant.

σ_{RN} = .402mm

Pooled mean square = .162mm^2

Left Mandibular First Molar

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	0.20	1	0.20	5.12	1.71
N	63.70	9	7.08	3.02	56.6
RN	1.05	9	.114		
TOTAL	64.95	19			

The R effect is not significant.

σ_{RN} = .354mm

Pooled mean square = .125mm^2

TABLE 32

ANALYSIS OF VARIANCE TO DETERMINE THE LANDMARK ERROR FOR THE RIGHT AND LEFT GONIONS USING THE W.R.U. METHOD

Right Gonion

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	0.02	1	0.02	5.12	N.S.
N	247.52	9	27.5	3.02	169.8
RN	1.60	9	.162		
TOTAL	249.14	19			

The R effect is not significant.

σ_{RN} = .402mm

Pooled mean square = .162mm^2

Left Gonion

S.V.	S.S.	D.F.	M.S.	$F_{.95}$	F
R	0.45	1	0.45	5.12	2.61
N	288.80	9	32.09	3.02	160.5
RN	1.55	9	.172		
TOTAL	290.80	19			

The R effect is not significant

σ_{RN} = .447mm

Pooled mean square = .200mm^2

S.V. = Source of Variation
S.S. = Sums of Squares
D.F. = Degrees of Freedom
M.S. = Mean Square
R = Two measurements
N = Random sample of ten skulls

TABLE 33

FINDINGS OF THE TEST FOR HOMOGENEITY OF THE ERROR VARIANCES FOR REPOSITIONING BY THE HARVOLD METHOD (COCHRAN TEST)

Zygomatico-frontal suture

$C = \frac{.137}{.199} = .688$ $C_{crit.} = .801$ Not significant

Pooled variance = .0995 20 D.F.

Zygoma

$C = \frac{.10}{.20} = .50$ $C_{crit.} = .801$ Not significant

Pooled variance = .10 20 D.F.

Maxillary First Molar

$C = \frac{.175}{.275} = .636$ $C_{crit.} = .801$ Not significant

Pooled variance = .1375 20 D.F.

Mandibular First Molar

$C = \frac{.287}{.412} = .697$ $C_{crit.} = .801$ Not significant

Pooled variance = .206 20 D.F.

Gonion

$C = \frac{.275}{.369} = .769$ $C_{crit.} = .801$ Not significant

Pooled variance = .1845 20 D.F.

TABLE 34

FINDINGS OF THE TEST FOR HOMOGENEITY OF THE ERROR VARIANCES FOR REPOSITIONING BY THE W.R.U. METHOD (COCHRAN TEST)

Zygomatico-frontal suture

$C = \frac{.025}{.050} = .50$ $C_{crit.} = .801$ Not significant

Pooled variance = .025 20 D.F.

Zygoma

$C = \frac{.15}{.212} = .708$ $C_{crit.} = .801$ Not significant

Pooled variance = .106 20 D.F.

Maxillary First Molar

$C = \frac{.312}{.599} = .523$ $C_{crit.} = .801$ Not significant

Pooled variance = .2995 20 D.F.

Mandibular First Molar

$C = \frac{.250}{.475} = .526$ $C_{crit.} = .801$ Not significant

Pooled variance = .2375 20 D.F.

Gonion

$C = \frac{.360}{.710} = .507$ $C_{crit.} = .801$ Not significant

Pooled variance = .355 20 D.F.

TABLE 35

FINDINGS OF THE TEST FOR HOMOGENEITY OF THE ERROR VARIANCES FOR RELOCATION OF CRANIOFACIAL LANDMARKS IN THE HARVOLD METHOD (COCHRAN TEST)

Zygomatico-frontal suture

Note: There was no error for the right and left zygomatico-frontal sutures.

Pooled variance = 0.00 20 D.F.

Zygoma

$C = \frac{.012}{.024} = .50$ $C_{crit.} = .801$ Not significant

Pooled variance = .012 20 D.F.

Maxillary First Molar

$C = \frac{.112}{.187} = .599$ $C_{crit.} = .801$ Not significant

Pooled variance = .0935 20 D.F.

Mandibular First Molar

$C = \frac{.062}{.112} = .554$ $C_{crit.} = .801$ Not significant

Pooled variance = .056 20 D.F.

Gonion

$C = \frac{.087}{.162} = .537$ $C_{crit.} = .801$ Not significant

Pooled variance = .081 20 D.F.

TABLE 36

FINDINGS OF THE TEST FOR HOMOGENEITY OF THE ERROR VARIANCES FOR RELOCATION OF CRANIOFACIAL LANDMARKS IN THE W.R.U. METHOD (COCHRAN TEST)

Zygomatico-frontal suture

Note: There was no error for the right and left zygomatico-frontal sutures.

Pooled variance = 0.00 20 D.F.

Zygoma

$C = \frac{.162}{.224} = .723$ $C_{crit.} = .801$ Not significant

Pooled variance = .112 20 D.F.

Maxillary First Molar

$C = \frac{.125}{.200} = .625$ $C_{crit.} = .801$ Not significant

Pooled variance = .100 20 D.F.

Mandibular First Molar

$C = \frac{.162}{.287} = .564$ $C_{crit.} = .801$ Not significant

Pooled variance = .1435 20 D.F.

Gonion

$C = \frac{.200}{.362} = .552$ $C_{crit.} = .801$ Not significant

Pooled variance = .181 20 D.F.

TABLE 37

COCHRAN TEST FOR HOMOGENEITY OF REPOSITIONING ERROR VARIANCE BETWEEN THE HARVOLD AND W.R.U. METHODS

Zygomatico-frontal suture

$C = \frac{.0995}{.1245} = .799$ $\quad C_{(2,\ 20).95} \leq .734$

$C_{.99} < .795$

Differences are significant.

Harvold $\sigma_{RN}^2 = .0995$ 20 D.F.

W.R.U. $\sigma_{RN}^2 = .025$ 20 D.F.

Zygoma

$C = \frac{.106}{.206} = .515$ $\quad C_{crit.} \leq .734, > .71$

Differences are not significant.

Pooled variance = .103 40 D.F.

Maxillary First Molar

$C = \frac{.2995}{.4370} = .685$ $\quad C_{crit.} \leq .734, > .71$

Differences are not significant.

Pooled variance = .2185 40 D.F.

Mandibular First Molar

$C = \frac{.2375}{.4435} = .536$ $\quad C_{crit.} \leq .734, > .71$

Differences are not significant.

Pooled variance = .22175 40 D.F.

Gonion

$C = \frac{.355}{.5395} = .658$ $\quad C_{crit.} \leq .734, > .71$

Differences are not significant.

Pooled variance = .270 40 D.F.

TABLE 38

COCHRAN TEST FOR HOMOGENEITY OF LANDMARK ERROR VARIANCE BETWEEN THE HARVOLD AND W.R.U. METHODS

Zygomatico-frontal suture

No difference

Pooled variance = 0.00 40 D.F.

Zygoma

$C = \frac{.112}{.124} = .903$ $C_{crit.} \leq .734$

Differences are significant.

Harvold $\sigma_{RN}^2 = .012$ 20 D.F.

W.R.U. $\sigma_{RN}^2 = .112$ 20 D.F.

Maxillary First Molar

$C = \frac{.10}{.1935} = .517$ $C_{crit.} \leq .734, > .71$

Differences are not significant.

Pooled variance = .0968 40 D.F.

Mandibular First Molar

$C = \frac{.1435}{.1995} = .719$ $C_{crit.} \leq .734, \simeq .719$

Differences are not significant.

Pooled variance = .0998 40 D.F.

Gonion

$C = \frac{.181}{.262} = .690$ $C_{crit.} \leq .734, > .71$

Differences are not significant.

Pooled variance = .131 40 D.F.

TABLE 39

COCHRAN TEST FOR HOMOGENEITY OF VARIANCE FOR THE HARVOLD VERSUS W.R.U. REPOSITIONING ERROR TERMS

Using all six variances

$$C = \frac{.2700}{.9153} = .2949 \qquad C_{(6,\ 40).95} \leq .2612$$

Hypothesis rejected

Using all five variances

(zygoma, Maxillary 6, Mandibular 6, gonion and Harvold zygomatico-frontal suture.)

$$C = \frac{.2740}{.9128} = .3001 \qquad C_{(5,\ 40).95} \leq .3066 > .300$$

Accept Hypothesis

Pooled variance = .1928

For repositioning errors there are two populations.

1. W.R.U. Zygomatico-frontal suture $\sigma_{RN}^2 = .025$ 20 D.F.
2. Harvold zygomatico-frontal suture, zygomas, Maxillary first molars, Mandibular first molars and gonions

$\sigma_{RN}^2 = .1928$ 180 D.F.

Total error

1. $\sigma_{RN} = .158$mm W.R.U. Zygomatico-frontal suture
2. $\sigma_{RN} = .439$mm All other

TABLE 40

COCHRAN TEST FOR HOMOGENEITY OF VARIANCE FOR THE HARVOLD VERSUS W.R.U. LANDMARK ERROR TERMS

Using all six variances

$C = \frac{.131}{.4516} = .2900$ $\quad C_{(6,\ 40).95} \leq .2612$

Reject Hypothesis

Using four variances

(W.R.U. zygoma, Maxillary 6, Mandibular 6, gonion)

$C = \frac{.131}{.4396} = .2980$ $\quad C_{(4,\ 40).95} \leq .3720 > .35$

Accept Hypothesis

For the landmark errors there are three populations.

1. Zygomatico-frontal sutures $\sigma_{RN}^2 = 0.0$ 40 D.F.
2. Harvold zygoma $\sigma_{RN}^2 = .012$ 20 D.F.
3. W.R.U. zygoma, Maxillary first molars, Mandibular first molars, gonions $\sigma_{RN}^2 = .1096$ 140 D.F.

Landmark Error

1. $\sigma_{RN} = 0.0$mm Zygomatico-frontal sutures
2. $\sigma_{RN} = .110$mm Harvold zygoma
3. $\sigma_{RN} = .331$mm All others

TABLE 41

THE REPOSITIONING ERROR TESTED AGAINST THE LANDMARK RELOCATION ERROR (HOMOGENEITY OF VARIANCE)

$$C = \frac{.1928}{.3024} = .638 \qquad C_{crit.(2,\ 180).95} = .5813$$

Hypothesis rejected - errors are different.

TABLE 42

COMPONENTS CONTRIBUTED TO TOTAL ERROR BY REPOSITIONING ERROR AND RELOCATION OF CRANIOFACIAL LANDMARK ERROR

Repositioning

$\sigma_{RN}^2 = .1928$

Landmark

$\sigma_{RN}^2 = .1096$

Repositioning error = Landmark variance + Repositioning variance

Error Components	Variance	Standard Deviation
Landmark	.1096	.331
Repositioning	.0832	.108
TOTAL	.1928	.439mm

56.8% of total variance is produced by Landmark error.

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