**ABSTRACT**

Various intra and extracranial cephalometric horizontal reference planes have been used to formulate diagnosis and plan individualized treatment for an integrated correction of the malocclusion.

**Aim:** The aim of this study was to evaluate variability of intracranial reference planes, i.e. sella-nasion, basion-nasion, Frankfurt horizontal, functional occlusal, mandibular and maxillary-mandibular bisector planes, in relation to the true horizontal plane in natural head position and their relationship to each other.

**Materials and methods:** For the present study, 100 subjects (50 males and 50 females) were selected between the age group of 17 and 25 years having pleasing profile with competent lips with Angle’s Class I molar relationship and normal overjet and overbite with no history of taking any form of orthodontic treatment.

**Results:** The data collected was statistically analyzed. Pearson’s correlation coefficient to quantify the strength of association between the pairs of angular variables was calculated. Their significance, i.e. p-value was set at p < 0.001.

Reproducibility for natural head position over a 2-month period was quantified by measuring the difference between the variable Frankfurt horizontal/true horizontal at initial (T1) and second (T2) recordings of the randomly selected subjects (n = 10). Significance for statistical test was set at p < 0.05.

The results inferred on studying the data for intraindividual natural head position reproducibility was that the reproducibility was less variable (more reliable) than the interindividual variability of craniofacial reference planes related to horizontal plane.

**Conclusion:** Among all the reference planes studied, the Frankfurt horizontal plane was closest to the true horizontal and thus could be recommended as a reference plane, when radiographs were not recorded in natural head position.

**Keywords:** Cephalometric, NHP, Malocclusion.

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**INTRODUCTION**

Since the advent of cephalometrics, various intra and extra-cranial reference planes have been introduced to study and measure facial proportions so as to qualify them as normal or deviation from normal with respect to the overall statistics taken of a population for that particular measurement, thereby planning treatment modalities for individual patients for an integrated correction of the malocclusion.

Among the various methods of recording the lateral cephalogram using cephalostat, the orientation of patients in natural head position (NHP) has been performed historically and even to the present day. NHP is a method to record details of the face from time as early as fifteenth century as reported in Leonardo’s work which included study of facial proportions in his drawing which also detailed the posture of an individual face in NHP.

Van Loon (1915) stipulated that, for a meaningful diagnosis and treatment planning, a 3D system was required to determine the relationship of dentition to face. For the orientation of the head in NHP, he devised a new method in which the cubus cranioforus (a device used by anthropologists to study crania that approximated the natural head position by orienting the head with reference to the Frankfort horizontal plane, i.e. the tragi of ears and landmark orbitale) was lowered over the patients head, keeping its base horizontal. Since this procedure was complex and time consuming, it was further modified by others, like Paul W Simon (1722) who replaced the cubus cranioforus with a face bow.

Broadbent, in 1931, introduced cephalometric radiography to obtain standardized head radiographs. This path breaking study brought orthodontists to the fore in an area which till then was monopolized by anatomists and anthropologists.

Contemporary cephalometric analysis in orthodontics is based on comparing elements of craniofacial morphology to selected reference planes. Ideally, a valid cephalometric reference plane system should have the following features good reliability (low method error), good intra-individual reproducibility, low inter-individual variability, and an average orientation close to true horizontal (HOR).
The use of intracephalic reference lines was probably developed to overcome the variation of head positioning within the cephalostat. Any analysis making use of a true horizontal must overcome, as far as possible, variation in the patient’s head position at the time of radiography. Many cephalostats incorporate a marker to locate externally the position of some point on the patient, usually orbitale or nasion, and the cephalostat ear-rods are often used as a marker for location of porion (Moyers, 1973). However, these markers only locate landmarks of certain intracephalic reference lines, which themselves may not bear a constant relationship to the true vertical. Therefore, the concept of natural head position during cephalography was developed, since clinical judgments are presumably related to some natural head posture.

To test the accuracy for recording NHP, reproducibility of NHP, when assessed as an error of a single observation, was close to 2°. Studies have suggested that the NHP has a clinically acceptable reproducibility and it has also been documented that true horizontal planes derived from NHP registration represent a more valid craniofacial reference system. Several authors have tested various intracranial reference planes for validity by evaluating interindividual variability and average orientation to HOR. Foster, Howat, Naish conducted a study to assess the variation in relationship of the sella-nasion, Frankfurt, maxillary and mandibular reference lines to a true horizontal and to each other. They found that these reference lines showed considerable variation both to each other and to a true horizontal.

The present study was conducted to evaluate the reproducibility of NHP, the relationship of the sella-nasion plane, basion-nasion plane, Frankfurt horizontal plane, functional occlusal plane, mandibular plane and maxillary-mandibular bisector plane to the true horizontal in natural head position and to evaluate the constancy of the relationship of these lines to each other.

AIM

The aim of this study was to evaluate variability of intracranial reference planes, i.e. sella-nasion, basion-nasion, Frankfurt horizontal, functional occlusal, mandibular and maxillary-mandibular bisector planes, in relation to the true horizontal plane in natural head position and their relationship to each other.

MATERIALS AND METHODS

For the present study, 100 subjects (50 males and 50 females) were taken who registered as outpatients at ITS Centre for Dental Studies and Research, Muradnagar, Ghaziabad.

The subjects were selected between the age group of 17 to 25 years having pleasing profile with competent lips who have not taken any form of orthodontic treatment and having all permanent teeth till second molar erupted. All subjects should have Angle’s Class I molar relationship with normal overjet and overbite.

A Planmeca Proline EC X-ray unit was used to take the cephalograms. Exposure parameters were taken as per the manufacture’s recommendations. The film distance to X-ray tube was fixed at 160 cm. Subject to film distance was 15 cm from the midsagittal plane.

A plumb line was made using 0.014 inch stainless steel wire of 60 cm length attached to a weight of 215 gm and was hung from the cephalostat to indicate the true vertical on the film (Fig. 1). Subjects were positioned in NHP using a combination of self balancing and eye focusing method as advocated by Solow and Tallgren. Self-balancing was achieved by letting the subject tilt the head backward and forward with decreasing amplitude to find the most relaxed position. The eye focusing method was achieved after the self-balancing position was established.

A mirror measuring 4 ft × 2 ft was placed two meters away and 3 ft above the ground level. The subject was asked to look at the reflection of his or her own eyes in the mirror. The ear rods of the cephalostat was adjusted to hold the head in NHP. The subject was asked to hold the teeth in maximum intercuspsation. The correct position was confirmed by checking the subject from the front. The nose piece was then placed in front of the nasion contacting the skin to establish support in the vertical plane.

After a final check-up, the radiograph was taken. The entire procedure took only 1 to 3 minutes. The tracing was done on a view box with masking tape used to secure the acetate film position over the radiograph and to the view box and landmarks were located and marked on the cephalogram.

The following angular measurements were taken:
1. Sella—nasion plane to the true horizontal plane.
2. Basion—nasion plane to the true horizontal plane.
3. Frankfurt horizontal plane to the true horizontal plane.
4. Mandibular plane to the true horizontal plane.
5. Functional occlusal plane to the true horizontal plane.
6. Maxillary mandibular bisector plane to the true horizontal plane.

Fig. 1: Patient with positioned ear rods and suspended plumb line
A Cephalometric Study of Various Horizontal Reference Planes in Natural Head Position

With the patient facing right, a clockwise rotation between two planes was defined as a positive value and an anticlockwise rotation a negative value. Out of the total 100 subjects, 10 were randomly selected and a second recording (T2) was made at an interval of 2 months from the initial recording (T1). Each lateral cephalogram was retraced to assess method errors and reproducibility of NHP.

Statistical Analysis

The data collected was statistically analyzed. Pearson’s correlation coefficient to quantify the strength of association between the pairs of angular variables was calculated. Their significance, i.e. p-value was set at p < 0.001.

Reproducibility for NHP over a 2-month period was quantified by measuring the difference between the variable FH/TH at initial (T1) and second (T2) recordings of the randomly selected subjects (n = 10). Significance for statistical test was set at p < 0.05.

RESULTS

The Table 1 shows interindividual variability of craniofacial reference planes to HOR which were expressed in terms of SD, range and coefficient of variation. The SD’s derived suggested that all six parameters showed variation from TH.

The least standard deviation among the six parameters was of FH-TH (3.1918), suggestive of it being the least variable among the six reference planes (Graph 1). The mean value for FH was –1.06 which indicates that it was closest to the true horizontal.

The SEM were least for FH-TH (0.4513) followed by SN-TH (0.4839) indicative of these planes having a low error value and thus better accuracy in recording with subjects in NHP. The values of SEM for the other planes were FOP/TH (0.5268), Ba-N-TH (0.5323), MM Bis (0.7132) and mandibular plane (0.9330).

The Table 2 shows measurements of 50 females for the six parameters studied. Similar results were obtained for mean, SD, SEM for the reference planes studied to that of the 50 males. FH-TH showed least variation having SD of (2.8128) followed by SN-TH (3.0211), MM Biss to TH (3.6927), FOP-TH (3.9099), Ba-N-TH (4.9785) and lastly showing maximum variation was mandibular plane to TH with a SD of 5.0233. The plane closest to the TH suggested by a low mean value was FH (1.94) followed by FOP (7.22), SN (8.14), mand plane (21.31) and finally Ba-N-TH (27.02). The error value for the six parameters was least for FH (0.3977) followed by SN (0.4272), MM Biss (0.5222), FOP (0.5529), Ba-N-TH (0.7041) and mand plane (0.7104). These errors reflect the variation in the consistency of these parameters. Thus, lesser the SEM better is its reproducibility. The mean age for females was 21.7 years.

Table 3 shows reproducibility of NHP measured by the difference of the variable—Frankfort horizontal (FH) to the true horizontal. For reproducibility of the planes, FH plane was selected for the study since it showed acceptable method errors results (0.4245).

The mean difference was calculated and tested for significance using t-test (0.0038). The SD of difference and mean square error S(i) (Dahlberg method) were found to be 1.2567 and 0.82835 respectively. Mean difference was close to zero (0.0015) and not statistically significant. The results inferred on studying the data for intraindividual NHP reproducibility was that the reproducibility was less variable (more reliable) than the interindividual variability of craniofacial reference planes related to HOR.

DISCUSSION

Natural head position (NHP) as a craniofacial reference system has been advocated because of its good intraindividual reproducibility. Short-term and long-term reproducibility of NHP has been confirmed by several authors 4,9,12,16 and it has been concluded that true vertical or horizontal planes derived from NHP registration represent a more valid craniofacial reference system. 5,11,13
However, the use of NHP is not widespread perhaps due to practical constraints, such as equipment and staff training. Thus, it may seem appropriate to use reference planes that are less variable between individuals and oriented closest to HOR.

The most commonly used intracranial reference planes are the sella-nasion (SN) and Frankfort horizontal (FH) planes. Frankfort horizontal which was originally adapted from anthropologic craniometric studies, has been the most commonly used reference plane for classification and considered by some to be the craniofacial reference plane most closely approximating the true horizontal, when the patient is in natural head position.\(^2,4,12\) According to Pancherz et al (1996)\(^{17}\) the machine porion was unsuitable for the construction of the FH. The machine porion was, on average, located approximately 9 mm below and 2 mm anterior to anatomic porion. A misjudgement of the reference line may result in diagnostic misinterpretations and lead to false conclusions in longitudinal studies, e.g. when the outcome of a particular treatment procedure is evaluated.

Another commonly used craniofacial reference plane is the sella-nasion plane (Broadbent, 1931).\(^3\) While this plane is reliable and also, by representing the anterior cranial base is biologically meaningful, it has been illustrated to have a large interindividual standard deviation (variation).

Maxillomandibular bisector (MMB) was proposed in 1994 by Hall-Scott.\(^{18}\) Located by bisecting the anterior angle that is formed by the intersection of the maxillary and mandibular planes, it does not rely on the dentition. It does not include cranial base landmarks, thereby eliminating potential problems with it.

The use of basion-nasion plane as an area of registration of overall evaluation of the dentofacial changes has been suggested by Rickett’s (1979).\(^{10}\) Since nasion, sella and basion move during growth, the method of overall superimposition on sella-nasion or basion-nasion lines have a low degree of validity, although they have a high degree of reproducibility.

Functional occlusal plane is represented by a line extending through the first molars and premolars.

Method error for the present study was calculated as described before and was found to be generally low. The standard error of mean was the least for FH (0.42) followed by SN plane (0.45), FOP (0.53), MM Bisector plane (0.61), Ba-N plane (0.61) and the mandibular plane (0.82). This was in contrast to the study by Madsen\(^4\) who found the standard error of mean least for SN followed by FH. These random errors were generally indicative of the reliability of the reference planes investigated.

Since the standard error of mean for FH (0.42) was the least, it was selected as a reference plane to calculate reproducibility of NHP.

Reproducibility in the present study (see Table 2) showed a standard deviation difference of 1.25, which was less than the study done by Madsen (2008),\(^4\) which showed SD difference of 2.99.

The mean square error of 0.82 which indicates NHP reproducibility over a 2-month period was sufficiently acceptable. Although on the lower side, this result is comparable with previous investigations of NHP reproducibility that report mean square error values ranging from 1.1 to 3.2°.

The present study showed a higher reproducibility of NHP compared to other studies. This might be due to the method employed to register NHP.

One of the main weaknesses in the use of NHP is its variable intraindividual reproducibility over time. With such variation in NHP registration, it may be difficult to establish whether it is head position or anatomic variation that is the primary contributor to variability of reference planes to horizontal. For this reason, a corrected head position has been advocated where NHP was deemed to be ‘unnatural’ (Moorrees and Kean, 1958).\(^4\)

From the present study, it is clear that the intraindividual reproducibility of NHP is less than the interindividual variation in the orientation of the craniofacial reference planes to horizontal. This validates the use of a true vertical or horizontal reference plane established from NHP registration in preference to other planes.

In a study conducted by Lundstrom and Lundstrom (1992),\(^{10}\) three cephalometric reference lines (sella-nasion, basion-nasion, and porion-orbitale) were compared with regard to their inclination to the horizontal plane. These angles showed

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### Table 2: The mean ± SD, SEM, CV, maximum and minimum values for six parameters studied in 50 females

<table>
<thead>
<tr>
<th>Sl no.</th>
<th>Measurement</th>
<th>Mean ± SD</th>
<th>Minimum</th>
<th>Maximum</th>
<th>SEM</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SN-TH</td>
<td>8.14 ± 3.0211</td>
<td>3</td>
<td>17</td>
<td>0.4272</td>
<td>37.114</td>
</tr>
<tr>
<td>2</td>
<td>FH-TH</td>
<td>−1.94 ± 2.8128</td>
<td>−9</td>
<td>6.5</td>
<td>0.3977</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Ba-N-TH</td>
<td>27.02 ± 4.9785</td>
<td>15</td>
<td>34</td>
<td>0.7041</td>
<td>18.425</td>
</tr>
<tr>
<td>4</td>
<td>MM Bis to TH</td>
<td>10.58 ± 3.6927</td>
<td>6</td>
<td>18</td>
<td>0.5222</td>
<td>34.9</td>
</tr>
<tr>
<td>5</td>
<td>FOP-TH</td>
<td>7.22 ± 3.9099</td>
<td>2</td>
<td>25</td>
<td>0.5529</td>
<td>54.15</td>
</tr>
<tr>
<td>6</td>
<td>Mand plane-TH</td>
<td>21.31 ± 5.0233</td>
<td>12</td>
<td>34</td>
<td>0.7104</td>
<td>23.57</td>
</tr>
</tbody>
</table>

### Table 3: Reproducibility of natural head position (NHP) [measured by the difference in the angular variable true horizontal (HOR) to Frankfort horizontal (FH) at the initial examination and follow-up]

<table>
<thead>
<tr>
<th>N (no. of subjects)</th>
<th>Mean difference</th>
<th>SD difference</th>
<th>t-test</th>
<th>p-value</th>
<th>S (i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.0015</td>
<td>1.2567</td>
<td>0.004</td>
<td>0.939</td>
<td>0.82835</td>
</tr>
</tbody>
</table>
standard deviations of between 4.5° and 5.6°. A strong correlation was found between the inclinations of the three cephalometric reference lines to the horizontal plane. The close anatomic relationship between these lines, in combination with the small random movements of the head around NHP, were believed to explain the covariation.

In the present study, due to the similar error values for FH and SN, the ability to locate relevant landmarks for both planes was similar. Also to be noted the fact that FH was on an average related more closely to HOR (mean being −1.15) compared to SN (mean being 7.33) which again reiterates the advantage of FH over SN as a reference plane with respect to variation (Graph 1). This is in contrast to the study done by Lundstrom and Lundstrom (1995) which noted that the standard deviation for the angle of FHP with true horizontal was too large for the FH to be considered reliable as a basis for clinical cephalometric analysis. Our study was in accordance with the study done by Madsen et al (2008) which reported that the visual inspection of the box plot distribution of data for the variables compared with HOR displayed the smallest distribution for HOR/FH and HOR/KW (Krogman–Walker line) (Rothstein and Yoon-Tarlie, 2000) showing their lowest variability with SDs of 4.63 and 4.67°, respectively as compared to another six variables (HOR/SN (sella-nasion), HOR/StN (sella tangent-nasion) (Sassouni, 1955), HOR/NHA (neutral horizontal axis) (McCarthy and Lieberman, 2001), HOR/P plane (palatal plane), HOR/FOP (functional oclusal plane), and HOR/PM plane (posterior maxillary plane) (Enlow and Azuma, 1975). The lowest value was 22° for HOR/P plane, while HOR/AtPt displayed the highest range of 34°.

CONCLUSION

The six craniofacial planes were traced to measure their angulations to the true horizontal and the data collected was subjected to statistical analysis. The following conclusions were drawn from this study:

1. The investigated craniofacial reference planes displayed larger interindividual variability than interindividual NHP reproducibility when both were related to true horizontal. Thus, a true horizontal plane from a NHP registration represents a more valid craniofacial reference system.

2. Among all the reference planes studied, the FH plane was closest to the true horizontal and thus could be recommended as a reference plane, when radiographs were not recorded in NHP.

REFERENCES