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Assessment of Reliability and Accuracy of Various Cephalometric Reference Planes Using Comparative Cephalometric Analysis

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Abstract:
Objective: *Various cephalometric reference planes have inherent shortcomings, due to which it becomes imperative to check the reliability of these planes with respect to true horizontal plane,which is the main aim of this study.*
Materials and methods: *Cephalometric radiographs of 90 subjects were selected and subjected to cephalometric analysis.Descriptive statistics including means and standard deviations were used to assess the variability of various planes.*
Results: *Frankfurt Horizontal plane followed by Krogman-Walker line shows least standard deviation with respect to true horizontal.In a separate comparison between Frankfurt Horizontal plane and Sella Nasion plane ,Frankfurt Horizontal plane showed less variability with respect to true horizontal.*
Conclusion: *Frankfurt Horizontal plane and Krogman-Walker line can be used reliabily as a cephalometric reference plane.*
Keywords: *Natural Head Position, Sella Nasion plane, Krogman-Walker line, Frankfurt Horizontal plane, Basion Nasion plane, True Horizontal.*

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I. Introduction:

Cephalometrics still remains cornerstone in orthodontic diagnosis and treatment planning.It is based on comparing various craniofacial measurements to certain reference planes. A reference plane can be considered accurate and if it satisfies certain criteria namely: reliability, close orientation to true horizontal or true vertical, good intra and intraindividual reproduceibility,easy identification of landmarks of reference planes. Reliability refers to the ability of the operator to identify and construct such reference planes with little systematic or random error on two or more successive occasions Intra-individual reproducibility refers to how the reference plane or system changes over time.The method of choice for orientation of patients for recording cephalograms is the natural head position (NHP) .This position has been performed historically and is relevant in the present time as well [1].Natural head position has been used to record craniofacial details around fifteenth century in Leonardo's work [1] of study of facial proportions.In order to orient the head in NHP Van Loon [1] devised cubus cranioforus which was a three dimensional system .It was replaced by face bow of Paul W Simon (1722) [2]. In the late 1950's [3,4,5] Natural head position (NHP) was introduced into orthodontics. Broca [6] defined this head position as "when man is standing and his visual axis is horizontal, he is in the natural position".NHP is registered most commonly by a method described by Solow and Tallgren[7].

In 1931 Broadbent, [8] introduced cephalometric radiography to obtain standardized head radiographs. This revolutionized the field of orthodontics and made the study of craniofacial region easier and brought orthodontists in an area which till then was monopolized by anatomists and anthropologists.Commonly used reference planes are SN plane and FH plane.Both of them have certain shortcomings which makes their use a reference plane questionable.This has been reported by various authors [3,4,5,7].

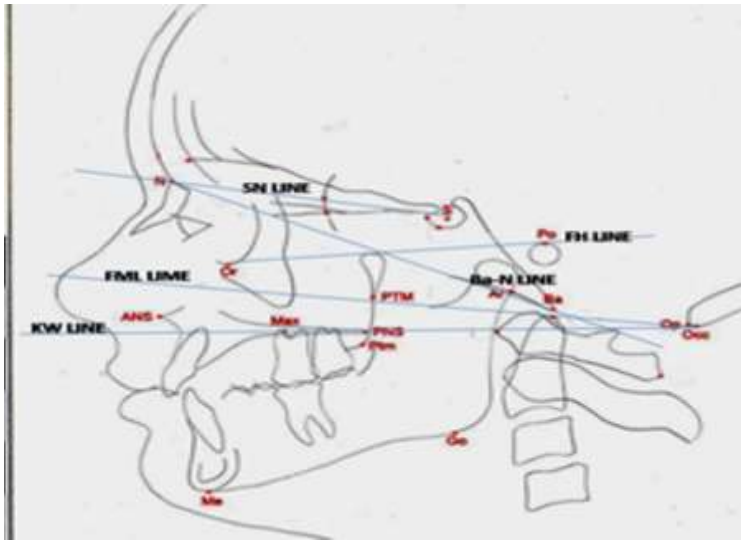
Various authors have conducted studies and have concluded that NHP has a clinically acceptable reproducibility and it has also been documented that true horizontal planes derived from NHP registration represent a more valid craniofacial reference system [9,10,11]. Björk [12] in 1950 published a paper on facial prognathism that highlighted the unreliability of intracranial reference lines in which two individuals who had

almost identical profiles but illustrated great difference in inclination of their cranial base rather than differences in prognathism were presented. Few studies have investigated the variability and average orientation of Krogman Walker line (KW line), foramen magnum line (FML) to the true horizontal. KW line [13], which passes from occipitale to maxillon, passes the oropharynx and, therefore, may possess a biological consistency to maintain the airway. Factors affecting NHP include: Craniofacial Morphology [14,15,16,] Walking[17], Respiratory Resistance [18-21], Rapid Maxillary Expansion[22,23], Orthognathic surgery [24] , Functional appliance[25], Craniomandibular disorder [26] , Altered vision [27].

.Hence the main aim of the study was to investigate the variability and average orientation of theses reference planes as well as other planes.i.e.SN plane, FH plane and Ba-N plane with true horizontal.

II. Materials And Methods:

The study was carried out on the patients received in the Out-Patient Department of the Department of Orthodontics & Dentofacial Orthopaedics, Government Dental College & Hospital, and Srinagar. The sample for this study consisted of 90 subjects which included 30 males and 60 females. Those subjects between the age group of 15-35 years, who did not undergo any prior orthodontic treatment and had a full complement of permanent teeth up to 2nd molars were selected for the study. It was ensured that the subjects selected had no caries or missing teeth, periodontal problem, TMJ abnormality any associated syndrome and had not undergone any surgery. Lateral standardized cephalograms were taken by a single operator using the same X-ray device and a standardized procedure,with cephalograms being taken in Natural Head Position based on the work of Solow and Tallgren [7]. The cephalograms were made with the mandible in the intercuspal position with an anode to midsubject distance of 5 feet.Thyroid shield and lead apron were worn by the subject to reduce radiation exposure.The procedure was approved by the ethical committee of the institution and a written consent was obtained from each participant. Lateral cephalogram was traced upon an A4 size acetate paper with a 2B or 3HB hard lead pencil over well-illuminated viewing screen. The linear measurements were recorded with a measuring scale up to a precision of 0.5mm . The angular measurements were analysed with a protractor up to a precision of 0.5°. The reference points and planes used are shown in Figure 1.



Articulare (Ar) - The point of intersection of the inferior cranial base surface and the averaged posterior surfaces of the mandibular condyles[28].

Basion (Ba) - The most inferior, posterior point on the anterior margin of foramen magnum [28].

Maxillon (Max) – A point just below (occasionally above) the zygomatic key ridge, midway between the upper and lower border of the palate[29].

Occipitale (Occ) – The lowest point on the occipital bone[29].

Opisthion (Op) - The posterior midsagittal point on the posterior margin of foramen magnum[28].

Orbitale (Or) - The lowest point on the average of the right and left borders of the bony orbit [28].

Porion (Po) - A point on the superior edge of the auditory canal[28].

Sella (S) - The centre of the pituitary fossa[28].
Nasion (N) - The junction of the frontonasal suture at the most posterior point on the curve at the bridge of the nose [28].
Frankfort Horizontal(FH)- A line from orbitale to porion[3].
Krogman-Walker Line(KW) – This is defined in Rothstein & Yoon-Tarlie[28] as the line passing through occipitale and maxillon
Sella-Nasion (SN) – Aline joining sella and nasion[28].
Foramen magnum line (FML) – A line joining Basion and Opsthion[28].
Basion-Nasion line-A line joining basion and nasion[28].
True horizontal line (HOR) – This was taken as a pure perpendicular plane to the true vertical recorded in the lateral head photograph. This was drawn through Ar[9].
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. Foramen magnum line to the true horizontal.
5. Krogman-Walker line to the true horizontal.

Since most commonly used reference planes are SN plane and FH plane it was decided to test the accuracy of these two planes independently by taking certain measurements from both the planes and then compaired with the same measurements taken from true horizontal.
Following measurements were taken:

1. Antero-posterior maxillary skeletal relation to cranial base as assessed in McNamara analysis by measuring distance of point A from Nasion perpendicular to FH plane.
2. Antero-posterior mandibular relation to cranial base as assessed in McNamara analysis by measuring distance of Pogonion from Nasion perpendicular to FH plane.
3. Growth pattern as assessed in Tweed analysis by measuring angular relationship between Frankfort Horizontal plane and Mandibular plane (Gonion–Menton line).
4. Antero-posterior maxillary skeletal relation to cranial base as assessed in Steiner's analysis by measuring angle SNA.
5. Antero-posterior mandibular relation to cranial base as assessed in Steiner's analysis by measuring angle SNB.
6. Growth pattern as assessed in Steiner's analysis by measuring angular relationship between SN plane ans mandibular plane (Gonion-Gnathion line).
7.

2.1: Statistical Analysis

The data collected was statistically analyzedusing mean and standard deviation. . Their significance, i.e. p-value was set at $p < 0.001$. Pearson's correlation coefficient to quantify the strength of association between the pairs of angular variables was calculated with $r > 0.8$ showing that reference planes are highly correlated .

III. Results

Table 1 shows variability of various craniofacial planes with respect to true horizontal.This variability is expressed in terms of standard deviations.FH plane shows the leastvariability with standard deviation of 3.01 and Foramen Magnum line shows maximum variability with standard deviation of 5.99 with respect to true horizontal.This suggests that Frankfurt Horizontal Plane is least variable and closest to true horizontal followed by plane Krogman Walker line.

Table 1: Descriptive statistics for angular variables:*

S.NO	VARIABLE	MEAN VALUE(^{0})	STANDARD DEVIATION
1.	**HOR-SN**	5.22	4.99
2.	**HOR-FH**	-2.01	3.01
3.	**HOR-BaN**	25.22	4.88

4.	**HOR-KW**	-2.99	4.55
5.	**HOR-FML**	3.33	5.99

* FML: Foramen Magnum line; KW line:Krogman-Walker line; FH plane:Frankfurt Horizontal plane; SNplane:Sella-Nasion plane; HOR:True Horizontal

Table 2 shows that following reference planes are highly correlated(r > 0.8):HOR-SN andHOR-BaN, HOR-FH and HOR-KW, HOR-FMLand HOR-KW in both males and females.Gender differences in other planes might explain anatomical differences in between genders.

Table 2: Pearson correlation coefficients for angular and linear variables*

VARIABLE	**FEMALE**				**MALE**			
HOR-SN	**HOR-FH**	**HOR-BaN**	**HOR-KW**	**HOR-FML**	**HOR-FH**	**HOR-BaN**	**HOR-KW**	**HOR-FML**
	0.78	0.84	0.89	0.59	0.82	0.81	0.77	0.49
HOR-FH	**HOR-SN**	**HOR-BaN**	**HOR-KW**	**HOR-FML**	**HOR-SN**	**HOR-BaN**	**HOR-KW**	**HOR-FML**
	0.78	0.46	0.90	0.69	0.82	0.53	0.95	0.46
HOR-BaN	**HOR-SN**	**HOR-FH**	**HOR-KW**	**HOR-FML**	**HOR-SN**	**HOR-FH**	**HOR-KW**	**HOR-FML**
	0.84	0.46	0.77	0.79	0.81	0.53	0.75	0.73
HOR-KW	**HOR-SN**	**HOR-FH**	**HO-BaN**	**HOR-FML**	**HOR-SN**	**HOR-FH**	**HO-BaN**	**HOR-FML**
	0.89	0.90	0.77	0.88	0.77	0.95	0.75	0.80

*Correlation coefficient (r > 0.8) showing high correlation.
FML: Foramen Magnum line; KW line:Krogman-Walker line; FH plane:Frankfurt Horizontal plane; SNplane:Sella-Nasion plane;

HOR:True Horizontal

It is evident from table 3 and table 4 that the difference between some parameters when measured from Frankfurt Horizontal plane, Steiners plane and true horizontal is more in case of Steiners plane than Frankfurt Horizontal plane but this difference is not statistically significant.

Table 3: Descriptive statistics when Frankfurt-Horizontal plane and true horizontal is used as reference plane*

S.NO	**VARIABLE(^{0})**	**MEAN(FH PLANE)**	**SD**	**MEAN(HOR)**	**SD**	**P-VALUE**
1.	**N to Pt.A – FH Plane**	1.46	2.88	1.47	2.58	0.502
2.	**N to Pog – FH Plane**	-3.99	4.61	-3.75	4.11	0.531
3.	**FMPA**	25.96	5.99	25.90	5.79	0.497

* Level of statistical significance set at P<0.001.
FH plane: Frankfurt Horizontal plane ;FMPA:Frankfurt mandibular plane angle; HOR: True Horizontal

Table 4: Descriptive statistics when Steiners plane and true horizontal is used as reference plane*

S.NO	**VARIABLE(^{0})**	**MEAN**	**SD**	**MEAN(HOR)**	**SD**	**P-VALUE**
1.	**SNA**	81.63	3.32	83.79	4.44	0.433
2.	**SNB**	79.33	2.77	81.69	3.79	0.426
3.	**MPA**	26.01	2.87	31.01	3.57	0.253

* Level of statistical significance set at P<0.001.
MPA :Steiner's mandibular plane angle; HOR: True Horizontal

IV. Discussion:

Any study involving study of craniofacial characteristics and posturing of head ,a standardized technique to position the head should be followed to reduce errors in cephalometrics. In this study, all lateral cephalometric radiographs were taken on the same cephalostat by the same operator to reduce the chances of errors.Various authors have advocated the use of Natural Head Position [3,4,7] but this position has certain limitations [30] like it is time consuming,operator sensitive.Results of this study show that all the reference planes had standard deviations from true horizontal suggesting that no reference plane is as reliable as true horizontal,but to use natural head position every time might not be practically possible. Frankfort

Horizontal plane and Krogman Walker line show least variability from true horizontal in the present study.This relation of Frankfort Horizontal plane with true horizontal plane is in agreement with other studies [4,5] .This is in contrast to the study done by Lundstrom and Lundstrom[31] which concluded 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 Very few studies have been conducted to assess the relation between true horizontal and

Krogman Walker line.Present study shows a standard deviation of around 5 degrees.This is in agreement with study conducted by Barbera [32]. In the present study Sella Nasion plane showed a considerable variability from true horizontal and hence it is observed from the study that Frankfurt Horizontal plane is more suitable reference plane than Sella Nasion plane. But the landmarks porion and orbitale of the FH plane may be more difficult to find on a cephalometric radiograph[33]. It is generally agreed in literature that the midpoint of sella turcica and nasion are easier to identify than the less accurate porion and orbitale. Hence it canbe concluded that SN is more accurate than FH, but various studies contain contradicting results [5,10,34].

Anatomic porion may be replaced with the ear-rod image to improve reproducibility when porion is not easily identifiable[8,11]. However, difficulty in placing the ear rods, a slight movement of the patient, and the thickness of the ear canal may affect the accuracy of this artificial landmark [35]. Pearsons correlation coefficient shows that some reference planes show a strong correlation due to sharing of a common anatomic landmark .e.g. HOR-SN andHOR-BaN.However some reference planes do not share a common anatomic landmark but still are strongly correlated .e.g. HOR-FH and HOR-KW.This might be due to a consistent spatial relation between these planes due to skeletal morphology.Since most commonly used reference planes used are Sella Nasion plane and Frankfurt Horizontal plane this study included a separate observations in relation to these two planes.Saggital position of maxilla, mandible and growth pattern were studied in relation to both these planes and true horizontal as well.It was observed that the differences were more for Sella Nasion plane and true horizontal than Frankfurt Horizontal plane and true horizontal but this difference is not statistically significant.This points out that Frankfurt Horizontal plane is slightly more reliable as a reliable as a reference plane.

V. Conclusions:

1. Cephalometric references show variability from true horizontal.
2. Among all reference planes Frankfurt Horizontal plane and Krogman Walker plane show least variability from true horizontal and can be used as a reference plane reliabily.
3. Among Frankfurt Horizontal plane and Sella Nasion plane, Frankfurt Horizontal plane is more reliable as is evident from a separate comparative analysis of these two planes with respect to true horizontal.

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