Optimal head position: A new frame of reference for cephalometric analysis

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Christopher Andrew Teeters

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Dr. Nanci De Felippe

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Dedication

This thesis is dedicated to my wife, Morghan Teeters, for her willingness to live apart and work hard to support the family while I completed this residency program. I could not have done this without you.

To my parents, Mary and Robert Teeters, who have always been relentless supporters as I worked toward my goals. I could not have been blessed with more loving parents.

To my sister, Robin Teeters, who has always been a continuous source of inspiration and support throughout my life.

To my son, Blake, and daughter, Ava for inspiring me in ways I never thought possible.

Abstract

Introduction: Facial considerations are important in any contemporary cephalometric analysis based on a soft-tissue paradigm, and head position is often an important component of these soft-tissue measurements. Natural head position (NHP) has long been used as the reference position for craniofacial morphology and it has been subject to great scrutiny due to its inherent variability. This study aims to determine if there is an operator-defined optimal head position (OHP) that is deemed the most pleasant, universal to all skeletal classifications, and parallel to Frankfort Horizontal (FH).

Methods: 31 subjects (10 orthodontists, 10 orthodontic residents, and 11 orthodontic staff members) were asked to take an online survey evaluating 9 soft-tissue rendering profile positions (2.5 degrees apart) of 30 different models ($N=31$, Power = 0.92). They were asked to indicate the most pleasant profile orientation and to disclose whether they were orthodontists, residents, or staff members.

Results: Chi-square tests and two one-sided t-test procedure (TOST) tests were performed to test the null hypotheses. All null hypotheses were rejected, therefore: (1) not all profile orientations were chosen with equal frequency. The most commonly chosen angle was 0 (about 30% of the choices, $p < 0.0001$) corresponding to the Helion-Canthion line (HC line) parallel to the floor and about 70% of the choices were within 2.5 degrees of the angle 0. There was no significant difference in the head orientations chosen by orthodontists, orthodontic residents, and staff members; (2) the three skeletal classes demonstrated a very similar pattern of angle choice, which was most often 0 ($p < 0.05$); and (3) the soft-tissue HC line and hard-tissue FH deviation resulted in a mean of deviation range of values within the limits of $\pm 0.5°$ ($p< 0.001$) denoting very high concordance between HC line and FH.

Conclusions: 70% of responders chose the orientation within one standard deviation consistent with HC parallel to the floor ($p < 0.001$). We noticed that the most commonly chosen angle was 0 for each of the three skeletal groups ($p < 0.05$), and that their frequency distributions of angle choice had very similar shapes. The suggested OHP reference plane

proved to be parallel to FH and it was deemed to be an esthetically pleasing and easily determined soft-tissue head orientation. We believe that OHP can be confidently and meaningfully used in contemporary cephalometric analyses. This head orientation may be obtained prior to taking pictures and radiographs (including CBCTs) or after the exposure, by rotating the picture or soft tissue rendering until the HC line is parallel to the floor.

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Review of the Literature

The ability of an individual to recognize an attractive face is inborn, but rendering this into defined treatment goals is problematic.[1] Facial considerations are important in any contemporary cephalometric analysis based on a soft-tissue paradigm, and head position is often an important component of soft-tissue measurements.[2] When studying an individual for orthodontic diagnosis and treatment planning, the findings may differ markedly depending on the reference lines chosen and the corresponding head orientation.[3] Therefore, a standard position for the head is not only important for lateral cephalometric analysis but also for landmark accuracy, reproducibility, and extra-oral pictures.

Ideally, a valid horizontal reference plane should have the following features: easily identifiable, not influenced by growth, aligns the head in the most esthetically pleasant position, universal to all persons regardless of skeletal classification or race, relates the hard-tissue to the soft-tissue, relates the horizontal dimension to the vertical dimension, and is both reliable and reproducible. The term pleasant is here used as "having qualities that express a harmonious, well-balanced, alert, and beautiful profile."

Natural head position (NHP) has long been used as the reference position for craniofacial morphology and it has been subject to great scrutiny due to its inherent variability.[3-5] NHP is described as the usual, balanced position of the head, which is adopted for viewing the horizon or an object at eye level.[3,4] Nonetheless, its reproducibility is questionable since several authors have discovered NHP registrations to have variable intra-individual reproducibility over time with variations up to six degrees.[4-8] The accurate recording of this position can be a cumbersome process.[9]

NHP is determined by many physiological factors including visual lighting reflexes, reflexes initiated by the earth's gravity and muscular proprioceptive stimuli, airway patency, temperature, personality, mood, and emotions.[4] Differences in head position can occur from occasional tensing of the patient resulting in head tilt that is not natural.[12] Several authors recommend correcting the natural head position if necessary.[3,5,6,12] This implies that NHP in practice is often treated as a "patient-defined, operator modified" position which is not clearly defined or reproducible.

The term Natural Head Posture (NHPosture) is also encountered in the literature. NHPosture refers to the physiologic position of the head and is determined while one makes a forward step from a standing to a walking posture.[3,12,13] This position is reproducible for the individual, but varies from person to person especially subjects with impaired upper airway function.

Another reference commonly used in cephalometric analysis is the Frankfort Horizontal (FH) plane. When cephalometric radiography was introduced in the 1930's, many methods were introduced to evaluate the configuration of the face using various reference lines.[3,12] It has been noted that FH best approximates the true horizontal orientation of the head.[3,10,14-17] Ricketts[12] stated that the points used to construct FH, namely Porion and Orbitale, have important biologic significance in that they are related to basic sensory organs and are considered to be "keys to the vital centers." The variation of Frankfort Horizontal in relation to the true horizontal to the earth's surface has been shown to vary slightly around zero degrees.[12] In the recent years, FH has been used less frequently due to the difficulty in accurately locating Porion on a standard cephalogram.[18] Cone Beam Computed Tomography (CBCT) has shown a marked increase in cephalometric image resolution and corresponding accuracy of locating cephalometric landmarks, especially Porion.[18-22] Cephalometric films made on older machines used the ear rod for positioning which has been shown to vary as much as an entire centimeter and this can lead to significant errors. If FH is to be used, it is important to emphasize that the true Porion must be sought, based on the true anatomical outline of the internal auditory meatus.

Other less popular horizontal reference planes used in cephalometrics are: the Neutral Horizontal Axis (NHA), Krogman-Walker Line (KW line), and Palatal Plane (P plane). Previous research has demonstrated that they are nearly parallel to FH. NHA is defined by the Orbital Margin point (OM) and the Tuberculum Sellae Inferior (Ti). OM and Ti are located at the superoinferior midpoint between the lower and upper orbital rims and on the anterior wall of the sella turcica approximately 2 mm inferior to tuburculum sellae, respectively.[23] Traditionally the Orbital Access point (OA), a point defined as the supero-inferior midpoint between the superior orbital fissures and the inferior rims of the optic canals, has been used as the posterior reference point of NHA but is not well defined on lateral cephalographs.[23-25] The KW line is defined as the line from Occipitale (Occ) to Maxillon (Max). Points Occ and Max are located at the lowest point on the occipital bone and the point just below (occasionally above) the Key Ridge (a craniometric point located externally at the lowest extent of the zygomaticomaxillary suture) midway between the upper and lower border of the palate, respectively. P plane is defined as the line connecting the Anterior Nasal Spine (ANS) to the Posterior Nasal Spine (PNS), the most posterior point at the sagittal plane on the bony hard palate.[5]

Finally, another horizontal reference plane commonly used is Sella-Nasion (SN). By definition, the SN plane is selected from point Sella, located by inspection in the center of sella turcica on the sphenoid bone, and point Nasion, located at the suture junction of the frontal bone with the nasal bone.[12] This reference line has been widely used as Sella and

Nasion are considered to be two of the most easily and predictably located points on a cephalogram, with minimal inter-operator variability. It has been shown, however, in that there is no statistically significant difference between location of the points comprising SN and those of FH when true Porion, and not the ear rod, was used. Although Nasion abides some anatomic significance to the face, Sella, in contrast, has none. In addition, although the SN plane bears significance to anatomy in that it is an approximation of the cranial base, the relationship of SN to the mandible is distant and thus bears little significance to the morphology of the mandible.[12]

Of all the reference line options listed above, finding out which horizontal line is the best is a difficult task. NHP is advantageous in that it has been shown to be relevant to craniofacial morphology,[24,25] future growth pattern,[26] and mode of respiration.[25,26] A significant disadvantage of NHP according to the findings of Peng[29] is that females, on average, tend to "look down" about 2.4° more after 15 years. According to the findings of Solow and Tallgren[30,31] and of Cook,[32] males tended to "look up" more by an average of 3° in repeat recordings. NHP can also vary up to 6° in repeated recordings.

The orientation of NHPosture has some important benefits. The true horizontal reference plane in NHPosture is less variable than other reference planes such as SN, and any variations that are seen represent a true-life appearance.[33] It has also been shown to be reproducible even after 15 years.[33] A limitation of this head position, although most studies suggest that NHPosture is a single, static position, it is truly a small range of positions that fluctuate around a mean posture position.[34,35]

The major advantages of using the FH reference plane include: (1) orientation of the palate, face, and chin can be described in relation to this reference; (2) it is located near the vital organs- Porion juxtaposes the semi-circular canals used in hearing and Orbitale is located on the inferior orbital rim which completes its size early in life; (3) it is closer to the structures most commonly being evaluated in facial harmony, most notably the positions of the maxilla and mandible; and (4) is a reliable reference frame for growth forecasting. FH has limitations, most notably in the difficulty of finding point Porion.[12] Fortunately, with the advent of CBCT technology and the use of true Porion rather than the ear rod commonly seen in historic cephalograms, the accuracy of locating Porion is markedly improved. Another limitation noted in the literature is that the standard deviation of FH to itself at a different time point and in relation to the true vertical is 5° to 6° with a variance of 25° to 36°,[27] which may account for large discrepancies in longitudinal evaluations if not properly traced.

SN is advantageous as it is comprised of two of the most consistently identifiable landmarks on a cephalogram for its end points, Sella and Nasion. SN has the disadvantage of being distant from the majority of reference structures in which we routinely measure.[12] SN, in contrast to FH, is oriented with the brain rather than the face and vital sense organs. The cranial base also can be tipped up or down depending on variations within the cranium itself, which can profoundly affect important angular measurements such as the mandibular plane angle and upper incisor inclination.[29] In addition, the effects of growth complicate the long-term evaluation of head position based on SN.[29] (see Table 1 for a summary of the advantages and disadvantages of four commonly used horizontal reference planes).

Horizontal Reference Plane	
Natural Head Position (NHP)	
Advantages	Disadvantages
Relevant to craniofacial morphology[25] Relevant to future growth pattern[26] Related to mode of respiration[27] Most commonly used Long history of use Reproducible[3]	Accurate recording cumbersome[11] Determined by many confounding physiological factors[6] Occasional tensing of the patient may affect accuracy[12] Females tended to "look down in repeated recordings[29] Males tended to "look up" in repeated recordings[32] Can vary up to 6 degrees in repeated recordings[5,6,7,8]
Natural Head Posture (NHPosture)	
Advantages	Disadvantages
Physiologic position[3] Reproducible for the individual[13] Less variable than other reference planes such as SN[33] Variations represent a true-life appearance[33] Reproducible even after 15 years[33]	Varies from person to person[13] Varies in subjects with upper airway function[26] Not static, but a small range of positions that fluctuate around a mean posture position[34]
Sella Nasion (SN)	
Advantages	Disadvantages
Sella and Nasion are two of the most accurate points to locate on a cephalogram. (S > Ar > Na)[35] Good reliability[7] Biologically meaningful as it is a good representation of the anterior cranial base[7]	Distant from the majority of reference structures routinely measured[13] Oriented with the brain rather than the face and sense organs[13] Cranial base angulation profoundly affects measurements[29] Effects of growth complicate long term evaluation[29] Great variability in SN line orientation[8] SN cannot be extrapolated from a photograph
Frankfort Horizontal (FH)	
Advantages	Disadvantages
Best approximates the true horizontal orientation of the head[10,15] Related to the basic sensory organs[13] Reliable reference frame for growth forecasting[13] Most reliable basis for a true vertical line[14] Located close to reference structures[13]	Difficult to locate point porion[13] (however, CBCT has shown a marked increase in cephalometric image resolution and accuracy in locating the landmark Porion.)[16-20]

Table 1. Advantages and disadvantages of the four most commonly used reference planes in orthodontic diagnosis and treatment planning.

This study’s goals are: (1) to create an operator-defined head position based on clearly identifiable soft-tissue landmarks that can be: (2) associated with the most pleasant profile position; (3) used regardless of skeletal classification (Angle class I, II, or III); and (4) has a predictable and constant relationship with FH. The null hypotheses of this study include the following: (1) There is equal preference for head orientation when orthodontic practitioners, orthodontic residents, and staff members are asked to orient a profile to the most pleasant position; (2) when sorting according to skeletal classification (Angle class I, II, or III), there is equal preference for most pleasant profile orientation despite the orthodontic background (practicing orthodontists, residents, or staff members); and (3) the soft-tissue reference here created will not be parallel to FH, a skeletal reference line.

Materials and Methods

The Human Subjects Committee from the University of Minnesota has determined that this study is exempt from review under federal guidelines 45 CFR Part 46.101(b) category #2 (surveys/interviews; standardized educational tests; observation of public behavior). IRB number 1202E10843.

Creation of operator-defined head position

In order to obtain equivalence to FH, 2 soft-tissue landmarks were thought to be equivalent to Porion and Orbitale. These landmarks were chosen on soft-tissue profile renderings of CBCT data utilizing Dolphin Imaging 3D software (version 11.5, Chatsworth, CA) as a reference line. The first soft-tissue landmark was defined as the location where the anterosuperior aspect of the helix of the ear attaches to the skin of the face and will be referred to as the point “Helion”. The second landmark is where the upper eyelid meets the lower eyelid, also known as the canthus, and will be referred to as the point “Canthion” (Figure 1).

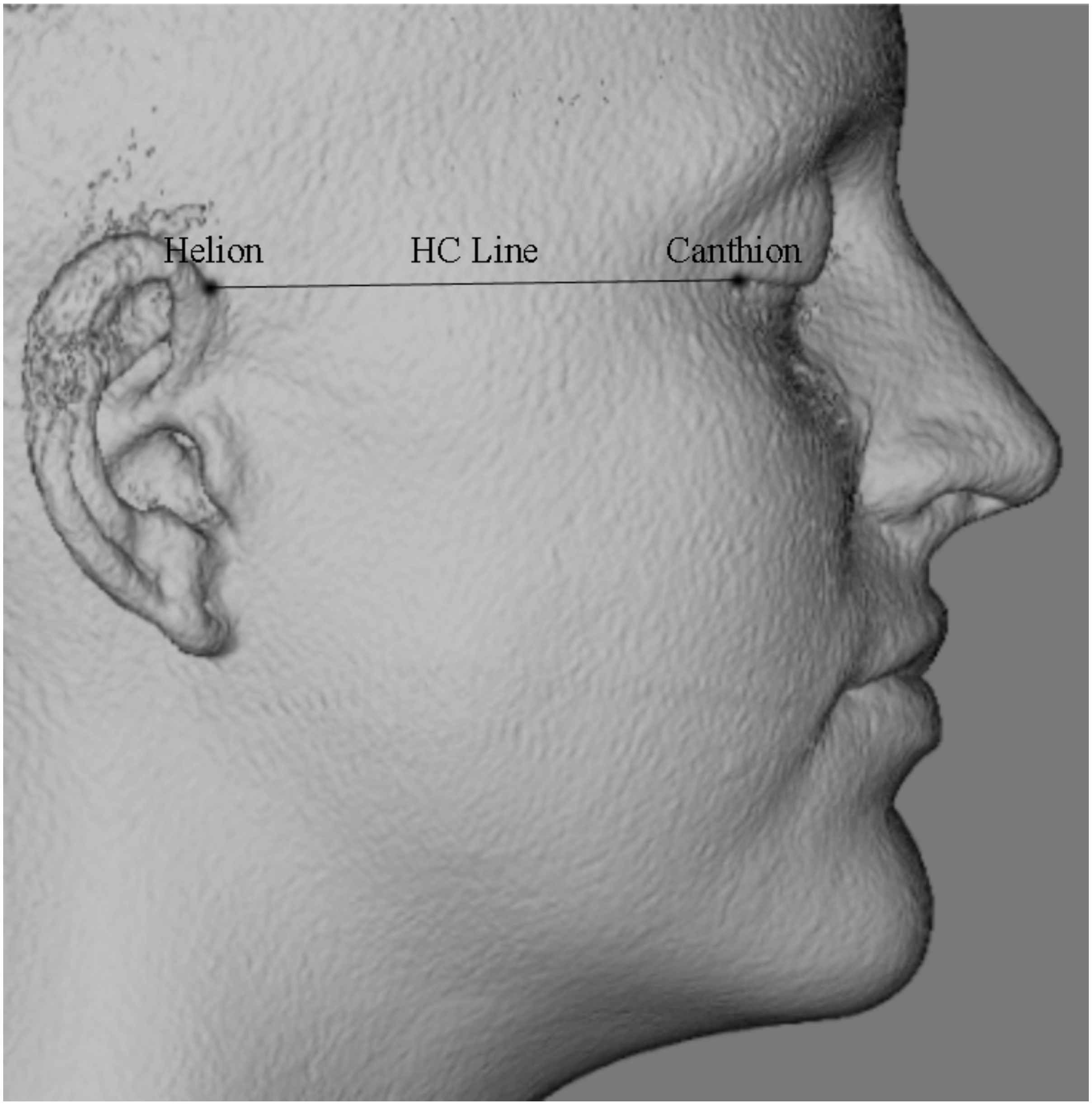


Figure 1. 3D soft-tissue rendering oriented with HC line parallel to the bottom of the film used to build the 2D lateral cephalograms. Point Helion (H) is defined as where the helix of the right ear inserts into the periauricular skin. Point Canthion (C) is defined as the union of the upper and lower eyelids, the outer canthus of the right eye. (Langsjoen E., personal communication)

The soft-tissue rendering should be oriented in space so that the points Helion and Canthion lie on the same horizontal plane. This was defined as the Helion-Canthion (HC) line, and is parallel to the inferior edge of the image (i.e. parallel to the floor). (Figure 2).

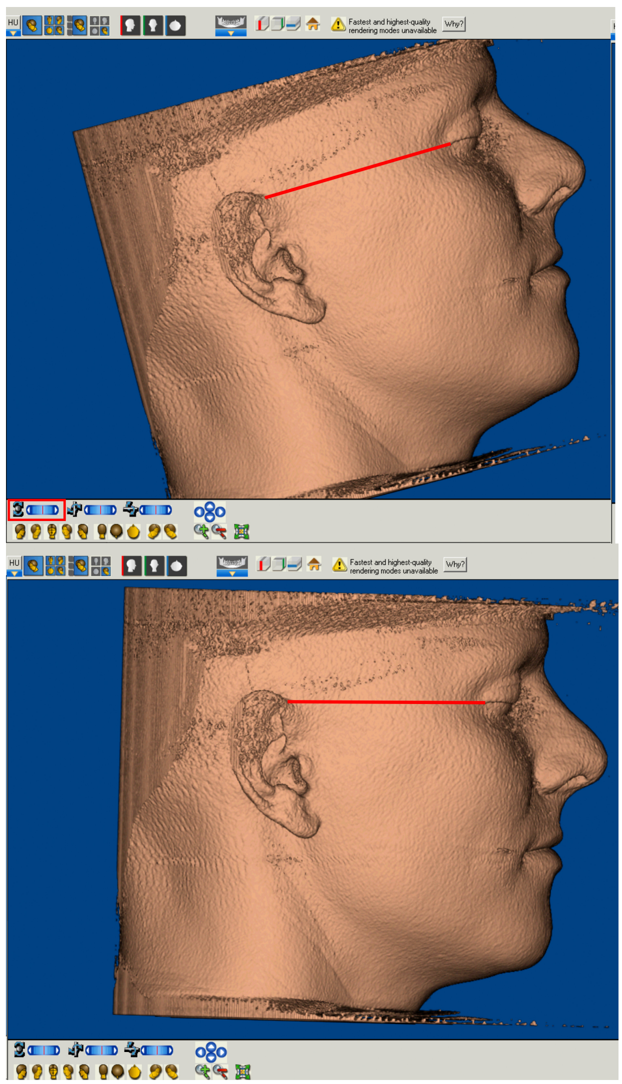


Figure 2. Use of the image rotation tool in Dolphin 3D imaging to orient the soft-tissue rendering of each patient with HC line parallel to the inferior edge of the image.

Online Survey Preparation

Consecutive pre-treatment CBCT volumes obtained in 2010 at the University of Minnesota were investigated for the following inclusion criteria: (1) absence of previous orthodontic treatment and (2) minimum age of 18 years old. The exclusion criteria were: (1) craniofacial variation with presence of syndrome or any congenital anomaly; (2) images that included a chin cup present to stabilize the head; (3) presence of lower facial hair (moustache or beard); (4) presence of jewelry (such as facial piercings); and (5) presence of motion artifacts.

A total of 30 CBCTs were selected and a TIFF image of the soft-tissue rendering was generated from each of the 30 CBCTs oriented to the HC line. Each image was imported into Adobe Photoshop (version 12.0.4, San Jose, CA). Nine different orientations of the head were constructed by using the image rotation tool. Images were constructed from 4 successive counter-clockwise increments of rotation and 4 successive clockwise increments of rotation of 2.5 degrees. The upper limit of the head-tilt was 10 degrees clockwise and, conversely, the lower limit was set at 10 degrees counterclockwise (Figure 3).

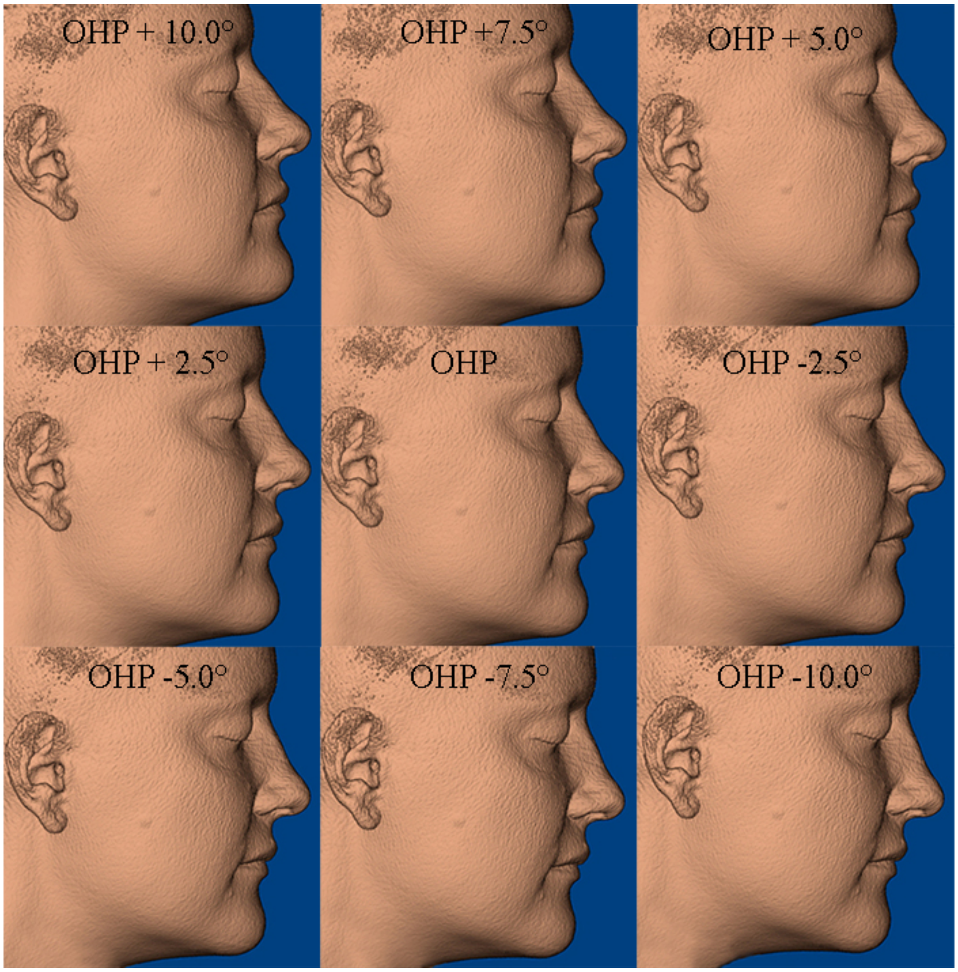


Figure 3. Successive increments of head rotation prior to randomization.

Each patient image was assembled into a montage of 9 orientations that were randomized using the software "list randomizer" (http://constantsun.com/tools/list_randomizer/?list=1%0D%0A2%0D%0A3%0D%0A4%0D%0A5%0D%0A6%0D%0A7%0D%0A8%0D%0A9%0D%0A&randomize=randomize). The 30 models each with

9 orientations were placed into a survey and administered through surveymonkey.com using the weblink: http://www.surveymonkey.com/s/9BJQ8BN. (Figure 4).

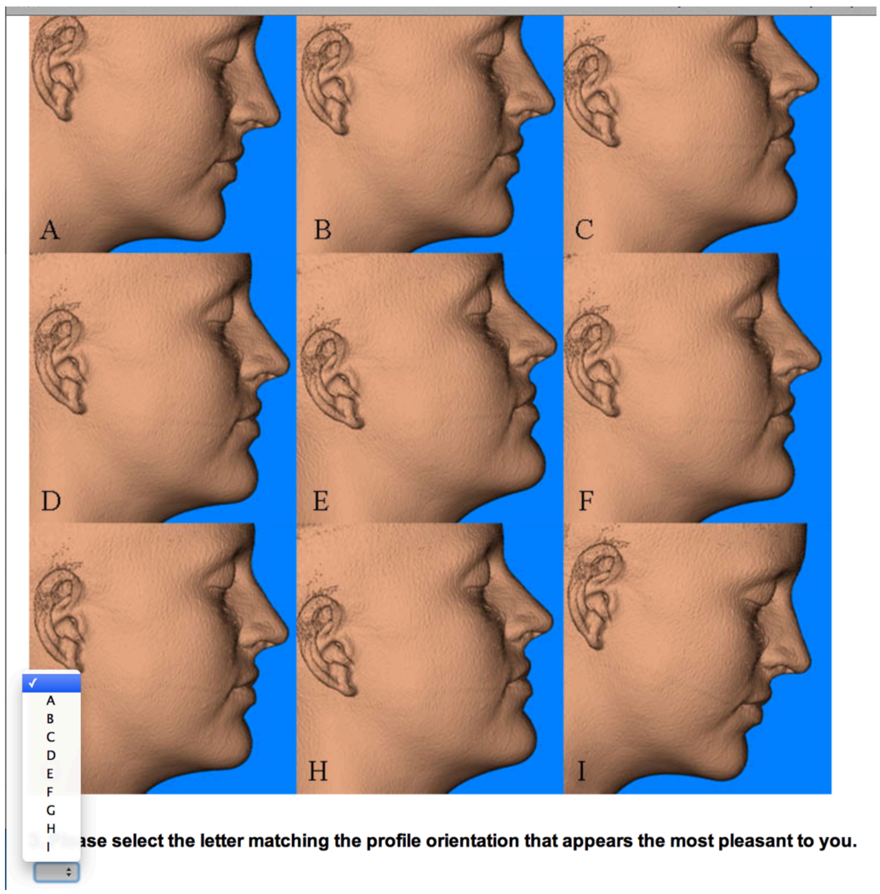
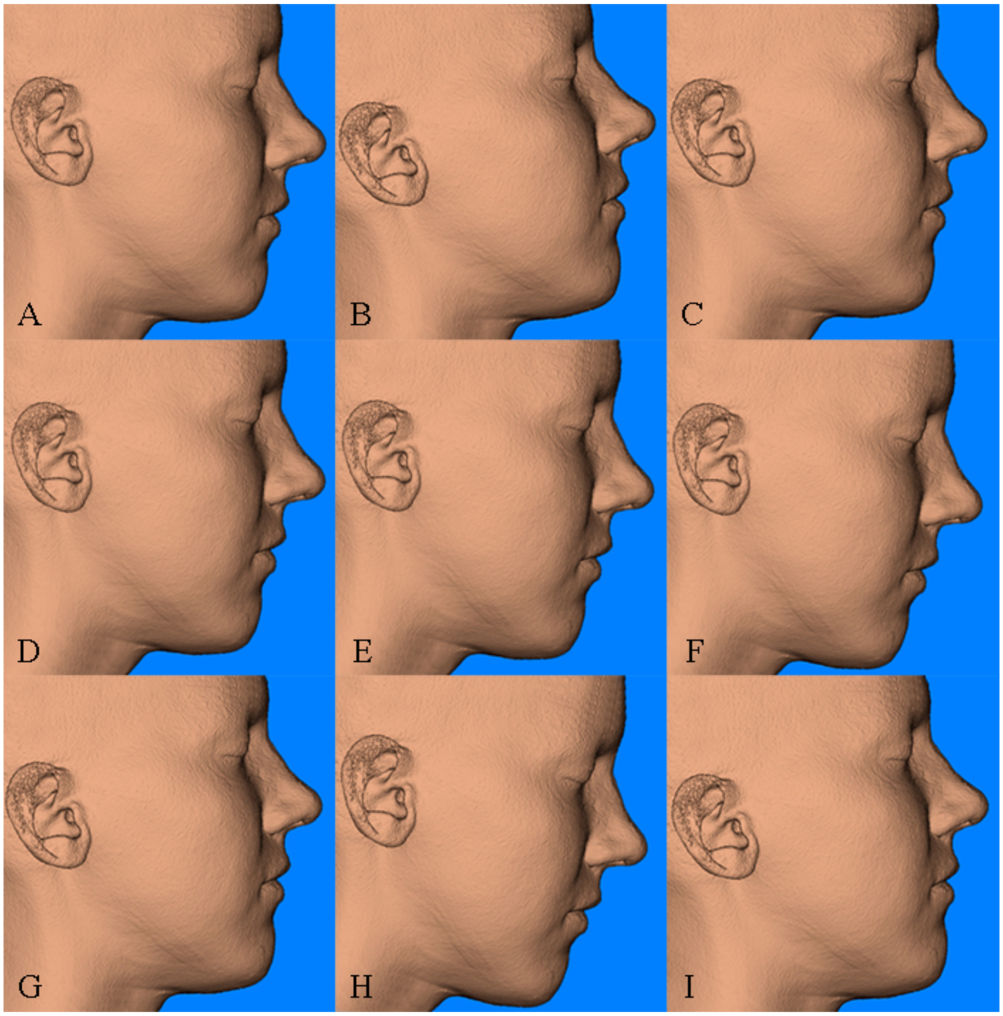


Figure 4. Example of one of the 30 montages used in the questionnaire.

Figure 5 illustrates 4 composites of varying skeletal classifications and profiles used in the study.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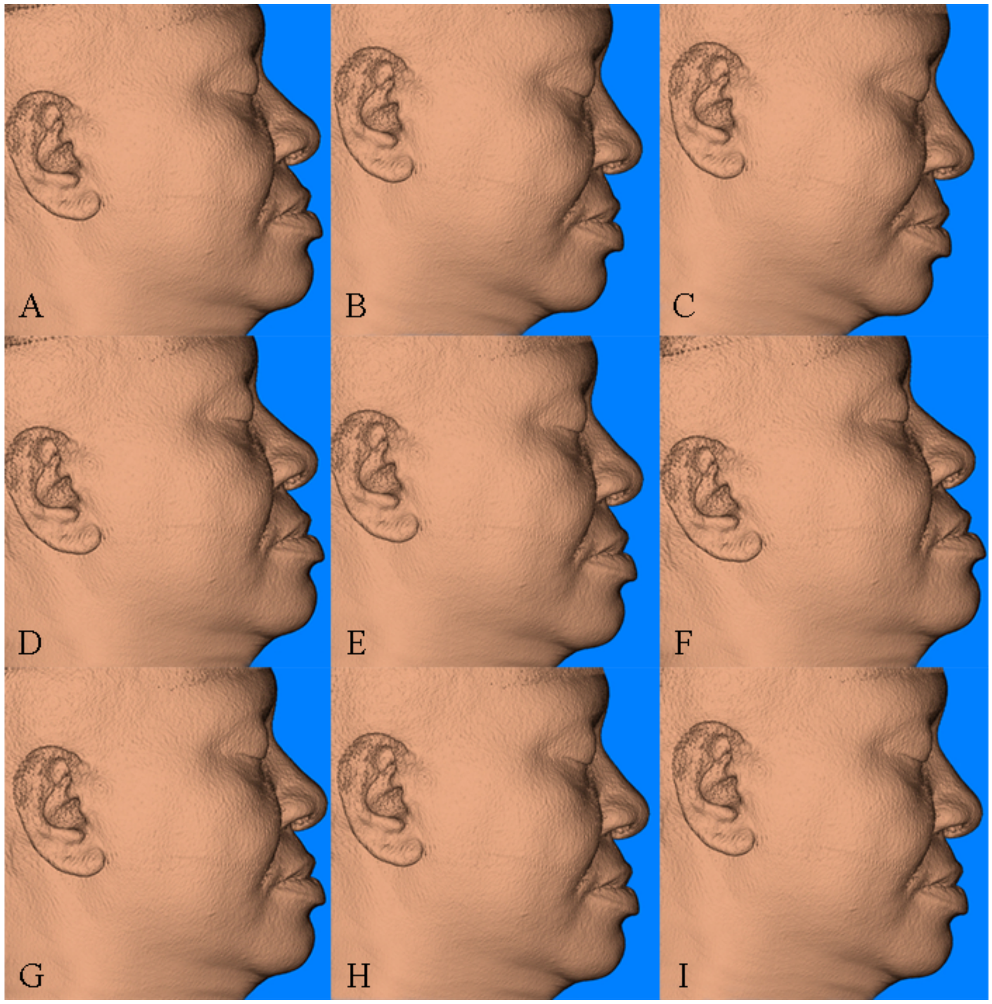
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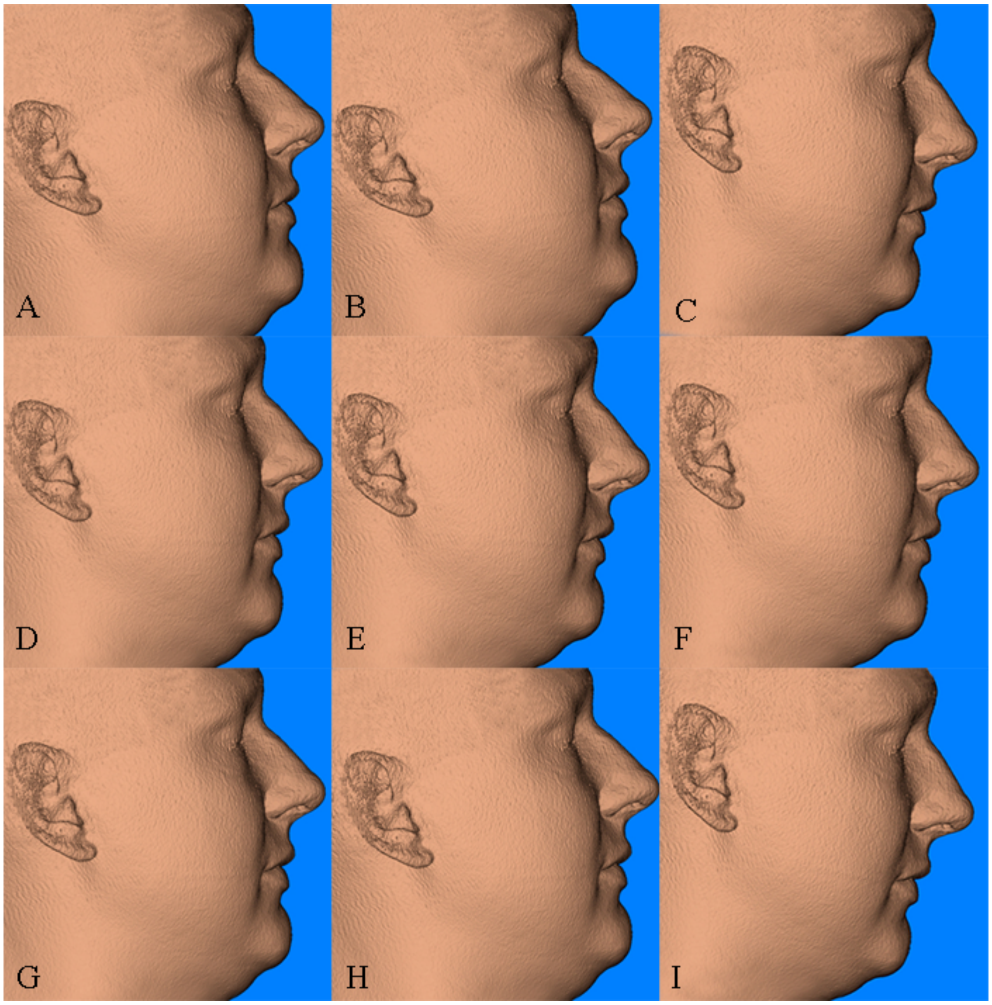
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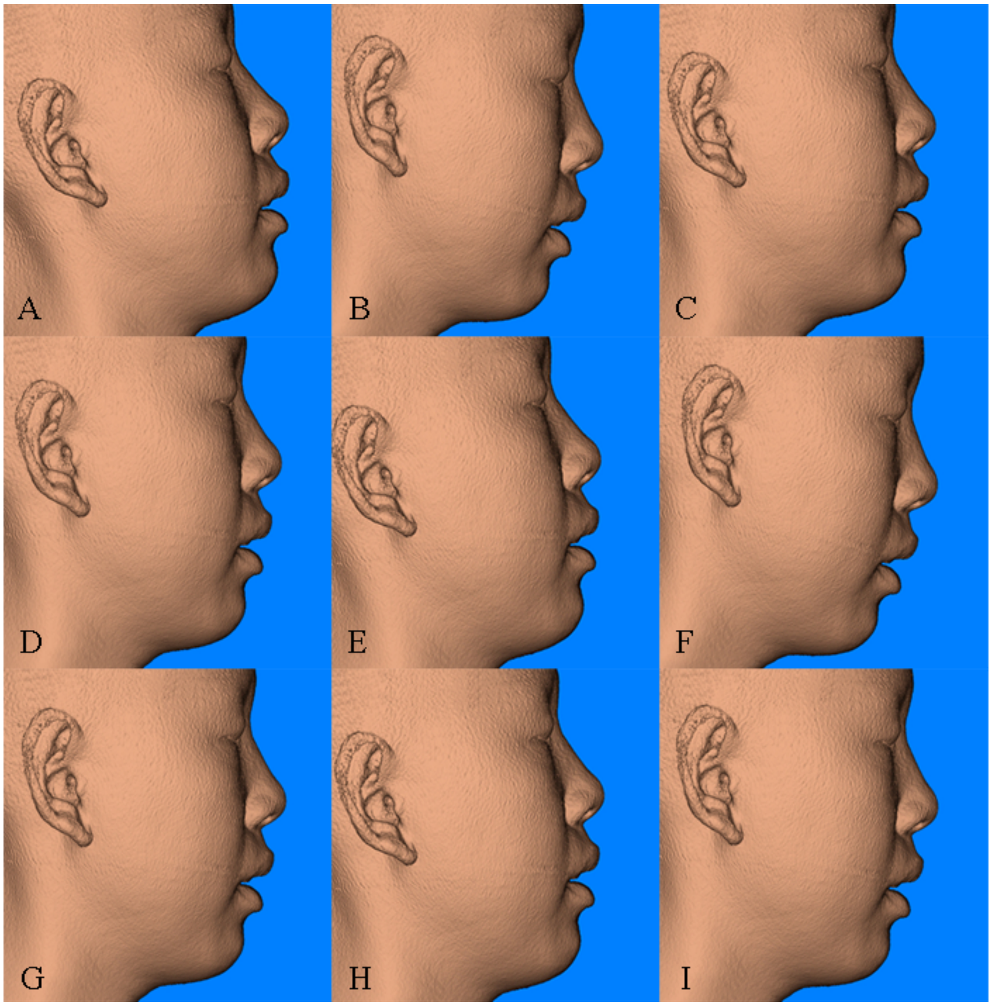


Figure 5. Example of 4 patient photo composites of varying skeletal classifications used in the questionnaire.

Survey Monkey was used to proctor the survey. The first question asked for the subject to identify his or her professional status (orthodontist, resident, or staff). The second question prompted the subjects to select the profile that appears most pleasant. There were no suggestions given or any additional information provided. Thirty such questions comprised the survey.

A pilot study was conducted with 10 third-year dental students at the University of Minnesota with 100% response rate to test the survey. Dental students taking an introduction to orthodontics course were invited to participate by answering a 30-question survey. No incentive was given for participation in the study. Each student was given a web link that traced a unique address from each computer and asked to complete the survey from his or her personal computer while in a lecture room. The pilot results were analyzed and only few minor modifications were deemed to be necessary.

This pilot study also served to calculate the needed sample size. An *a priori* power analysis was conducted and a sample size needed for 0.80 power was calculated to be 23 subjects.

Sample

Thirty-eight total subjects which included 13 orthodontists, 12 orthodontic residents, and 13 staff members were invited to participate in the final survey by e-mail. Every subject invited to participate responded to the survey, but only 10 orthodontists, 10 orthodontic residents, and 11 staff members identified their professional status, a mandatory question in order to proceed with the survey (N=31, Power=0.92). Subjects were individually asked to identify which one of the 9 orientations appeared the most pleasing to them for each of the 30 models. Responses were collected and summarized by the Survey Monkey output, indicating the frequency of each head orientation being chosen.

Analysis

1) Most pleasant head position - general

The frequencies of the chosen head orientations were assessed according to a chi-square test with respect to the null hypothesis (H0) that all angles are chosen with equal frequency among orthodontists, residents, and staff members.

2) Most pleasant head position – according to skeletal classification.

The skeletal classification for each of the 30 models was determined according to the angle formed by A point, Nasion, and B point (ANB) and the relationship of the A and B points to the occlusal plane (Wits appraisal). Seven of the 30 cases had a classification discrepancy between the ANB and Wits analysis. A panel of three orthodontic faculty at the University of Minnesota, who used other measurements to aid their classification, analyzed these cases to determine the final skeletal classification used in the study. The consensus determined the final skeletal classification to be the majority of the choices. The chi-squared test was utilized to determine if the type of skeletal classification affected the angular distance from the CH line chosen by the respondents.

3) OHP relationship with FH

The 3D soft-tissue renderings for each patient was re-aligned to OHP, with the HC line parallel to the inferior edge of the image. This was accomplished by using the orientation feature in Dolphin Imaging 3D software (version 11.5, Chatsworth, CA). A software-generated grid was activated and the profile rendering was rotated with the volume rotation tool until there was a straight grid line connecting points Helion and Canthion. After orienting, the build radiographs tool in Dolphin Imaging 3D software (version 11.5, Chatsworth, CA) was used to extract a lateral cephalometric radiograph from each of the 30 models in this orientation. Each radiograph was digitally traced, or "digitized", to be analyzed (Figure 6) by one trained operator with particular attention to selecting the landmarks Porion (the most superior aspect of the external auditory meatus) and Orbitale (the most inferior point on the orbital rim).

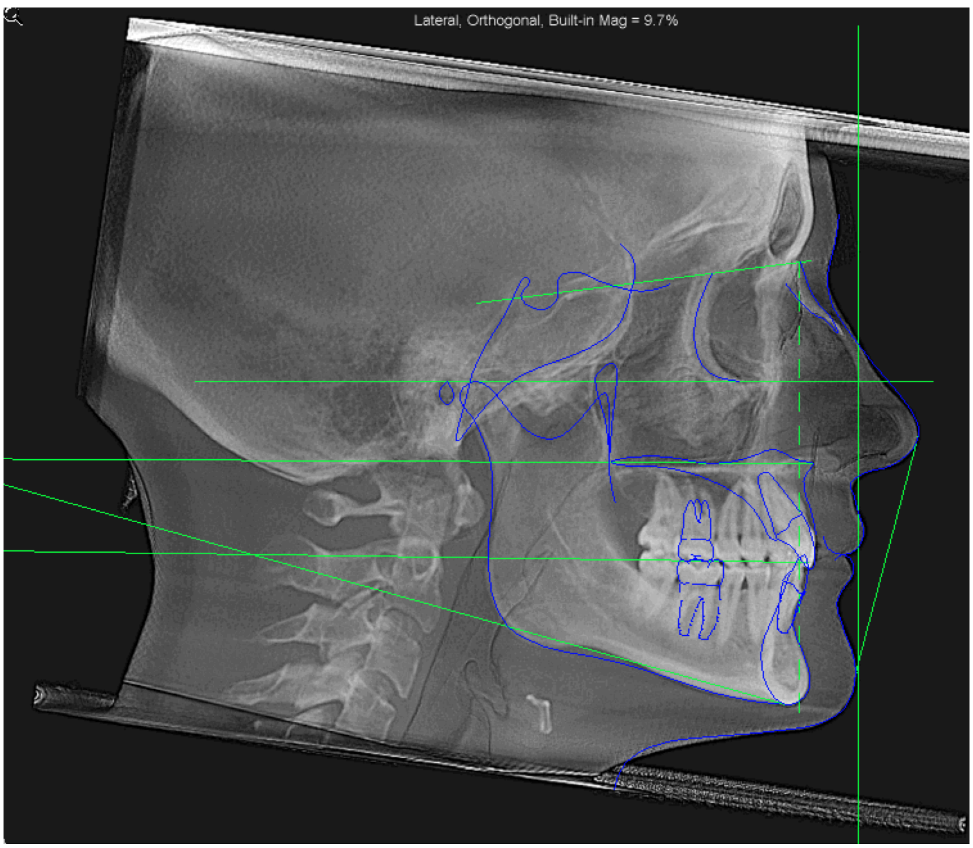
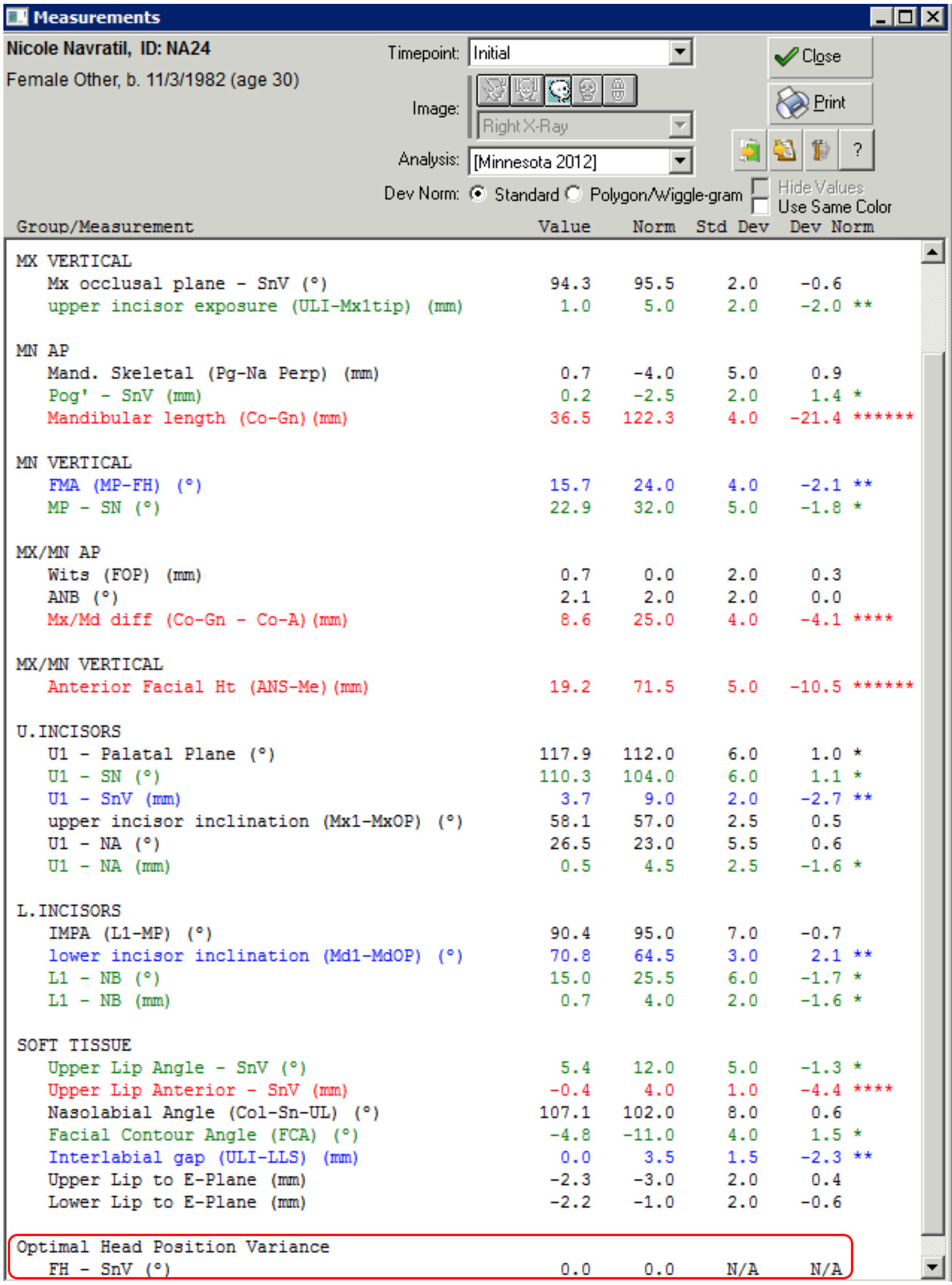


Figure 6. 2D lateral cephalogram generated from a 3D CBCT rendering with the head oriented in OHP. Digitized using the Minnesota 2012 analysis in Dolphin 3D software. This cephalogram also shows a generated vertical line unique to the patient, subnasale vertical (SnV), with the head in this orientation to which soft-tissue measurements can be made.

A new analysis under the title "Minnesota 2012" was created in Dolphin Imaging software (version 11.5, Chatsworth, CA) and contains an assessment known as "Optimal Head Position variance" (Figure 7). This variable was designed to measure the angular difference between FH and the inferior edge of the image. By orienting the soft-tissue to HC line, the hard-tissue tracing of FH can be compared to the soft-tissue orientation of OHP. A measurement in degrees is calculated under the "optimal head position variance" variable. Each of the values for the 30 models was collected and the two one-sided t-test (TOST) procedure was used to determine the deviations between the soft-tissue HC lines and the hard-tissue FH lines.

The two one-sided t-test (TOST) equivalence analysis was used to determine the angular difference, in degrees, between the HC line measured on the soft-tissue rendering of the model and FH measured on the lateral cephalometric radiograph generated from the CBCT image.



Measurements

Nicole Navratil, ID: NA24
Female Other, b. 11/3/1982 (age 30)

Timepoint: Initial
Image: Right X-Ray
Analysis: [Minnesota 2012]
Dev Norm: Standard / Polygon/Wiggle-gram
Hide Values / Use Same Color

Group/Measurement	Value	Norm	Std Dev	Dev Norm
MX VERTICAL				
Mx occlusal plane - SnV (°)	94.3	95.5	2.0	-0.6
upper incisor exposure (ULI-Mx1tip) (mm)	1.0	5.0	2.0	-2.0 **
MN AP				
Mand. Skeletal (Pg-Na Perp) (mm)	0.7	-4.0	5.0	0.9
Pog' - SnV (mm)	0.2	-2.5	2.0	1.4 *
Mandibular length (Co-Gn)(mm)	36.5	122.3	4.0	-21.4 ******
MN VERTICAL				
FMA (MP-FH) (°)	15.7	24.0	4.0	-2.1 **
MP - SN (°)	22.9	32.0	5.0	-1.8 *
MX/MN AP				
Wits (FOP) (mm)	0.7	0.0	2.0	0.3
ANB (°)	2.1	2.0	2.0	0.0
Mx/Md diff (Co-Gn - Co-A)(mm)	8.6	25.0	4.0	-4.1 ****
MX/MN VERTICAL				
Anterior Facial Ht (ANS-Me)(mm)	19.2	71.5	5.0	-10.5 ******
U.INCISORS				
U1 - Palatal Plane (°)	117.9	112.0	6.0	1.0 *
U1 - SN (°)	110.3	104.0	6.0	1.1 *
U1 - SnV (mm)	3.7	9.0	2.0	-2.7 **
upper incisor inclination (Mx1-MxOP) (°)	58.1	57.0	2.5	0.5
U1 - NA (°)	26.5	23.0	5.5	0.6
U1 - NA (mm)	0.5	4.5	2.5	-1.6 *
L.INCISORS				
IMPA (L1-MP) (°)	90.4	95.0	7.0	-0.7
lower incisor inclination (Md1-MdOP) (°)	70.8	64.5	3.0	2.1 **
L1 - NB (°)	15.0	25.5	6.0	-1.7 *
L1 - NB (mm)	0.7	4.0	2.0	-1.6 *
SOFT TISSUE				
Upper Lip Angle - SnV (°)	5.4	12.0	5.0	-1.3 *
Upper Lip Anterior - SnV (mm)	-0.4	4.0	1.0	-4.4 ****
Nasolabial Angle (Col-Sn-UL) (°)	107.1	102.0	8.0	0.6
Facial Contour Angle (FCA) (°)	-4.8	-11.0	4.0	1.5 *
Interlabial gap (ULI-LLS) (mm)	0.0	3.5	1.5	-2.3 **
Upper Lip to E-Plane (mm)	-2.3	-3.0	2.0	0.4
Lower Lip to E-Plane (mm)	-2.2	-1.0	2.0	-0.6
Optimal Head Position Variance				
FH - SnV (°)	0.0	0.0	N/A	N/A

Figure 7. Output of the Minnesota 2012 analysis. Optimal Head Position Variance variable shown at the bottom of the analysis and highlighted with a red box. (Langsjoen E., personal communication)

Results

1) Most pleasant head position - general

The means and standard deviations for the preferred head orientation chosen by orthodontists, orthodontic residents, and lay people were -0.250° ± 3.591°, 0.401° ± 3.329°, and 0.848° ± 3.591°, respectively. (Table 2 and Figure 8).

	Orthodontists	Residents	Staff Members
N	10	10	11
Mean	-0.250°	0.401°	0.848°
Standard Deviation	±3.591°	±3.329°	±3.591°

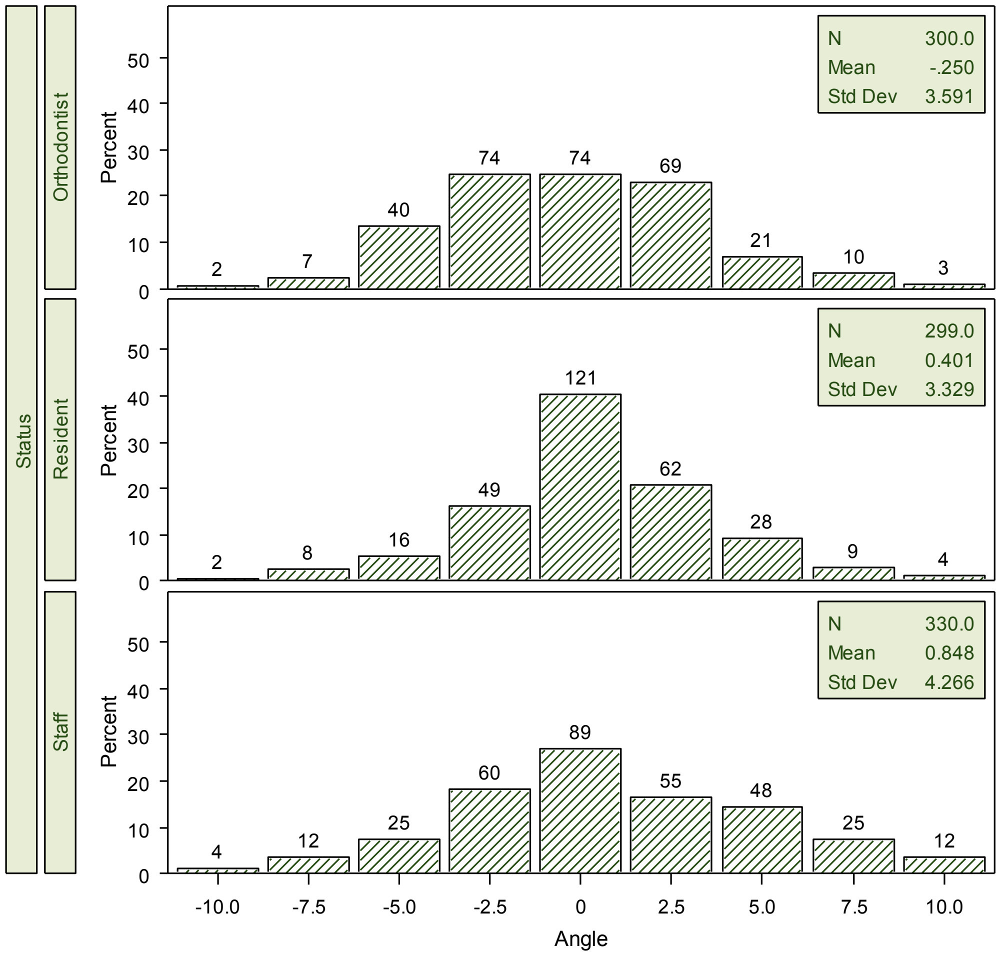


Table 2 and Figure 8. Descriptive statistics of the sample.

The frequency of the chosen head orientation yielded a chi-square test of equal proportions value of 696.6286 ($p < 0.0001$). Since $p < 0.0001$, the null hypothesis was rejected concluding that not all angles are chosen with equal frequency. The most commonly chosen angle was 0 (about 30% of the choices) and about 70% of the choices were within 2.5 degrees of the angle 0 corresponding to the HC line parallel to the floor. There was no significant difference in the head orientations chosen by orthodontists, orthodontic residents, and staff members. Descriptive analysis of the frequency of the various head orientations chosen is shown in Table 3 and Figure 9.

The FREQ Procedure

Angle	Frequency	Percent	Cumulative Frequency	Cumulative Percent
-10	8	0.86	8	0.86
-7.5	27	2.91	35	3.77
-5	81	8.72	116	12.49
-2.5	183	19.70	299	32.19
0	284	30.57	583	62.76
2.5	186	20.02	769	82.78
5	97	10.44	866	93.22
7.5	44	4.74	910	97.95
10	19	2.05	929	100.00

Chi-Square Test for Equal Proportions	
Chi-Square	696.6286
DF	8
Pr > ChiSq	<0.0001

Sample Size = 929

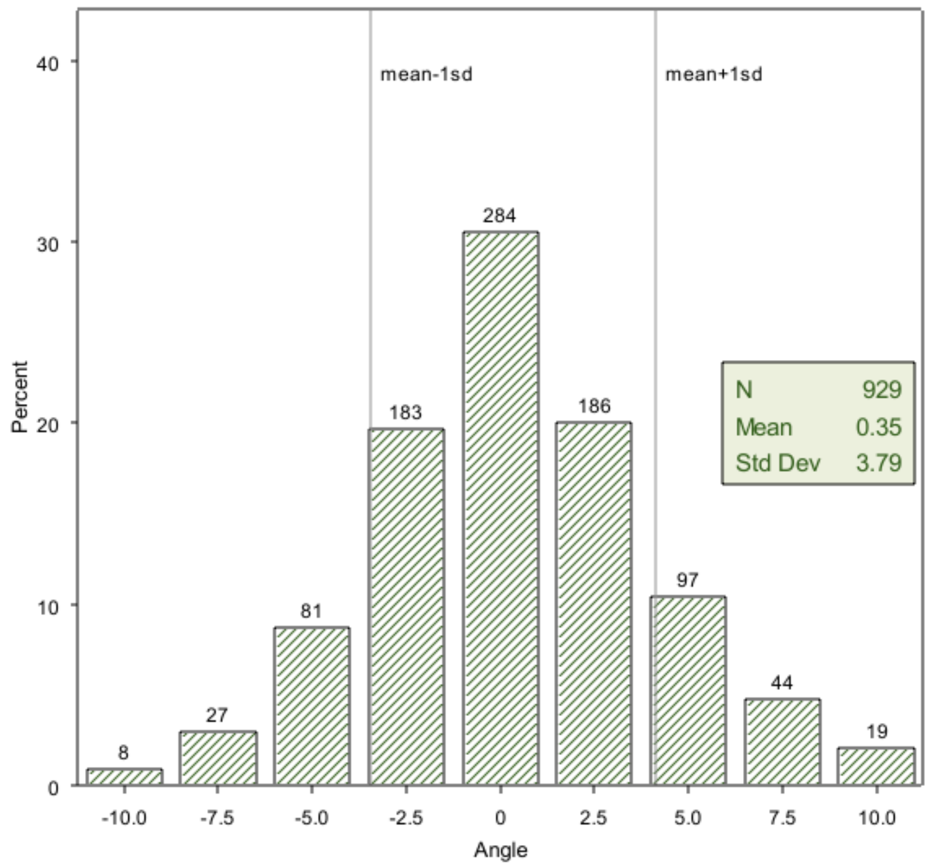


Table 3 and Figure 9. Frequency, means, and histogram for head orientation preference.

2) Most pleasant head position – according to skeletal classification

Next, a chi-square test was conducted with respect to the null hypothesis that skeletal classification and angle choice are independent (Chi-square = 26.3809, p = 0.04809). Since $p < 0.05$, the null hypothesis was rejected concluding that the three skeletal classes had the same pattern of angle choice. The most commonly chosen angle is 0 for all Class I, II and III groups. The frequency distributions of angle choice have very similar shapes (Table 4 and Figure 10) despite the skeletal classification.

Nonetheless, the p value was very close to 0.05 and one can argue that the null hypothesis should not be rejected. We decided to reject the null hypothesis because the power of our sample was high at 0.92 and we were confident that the findings from our survey represent the true opinions of our respondents, not just causality.

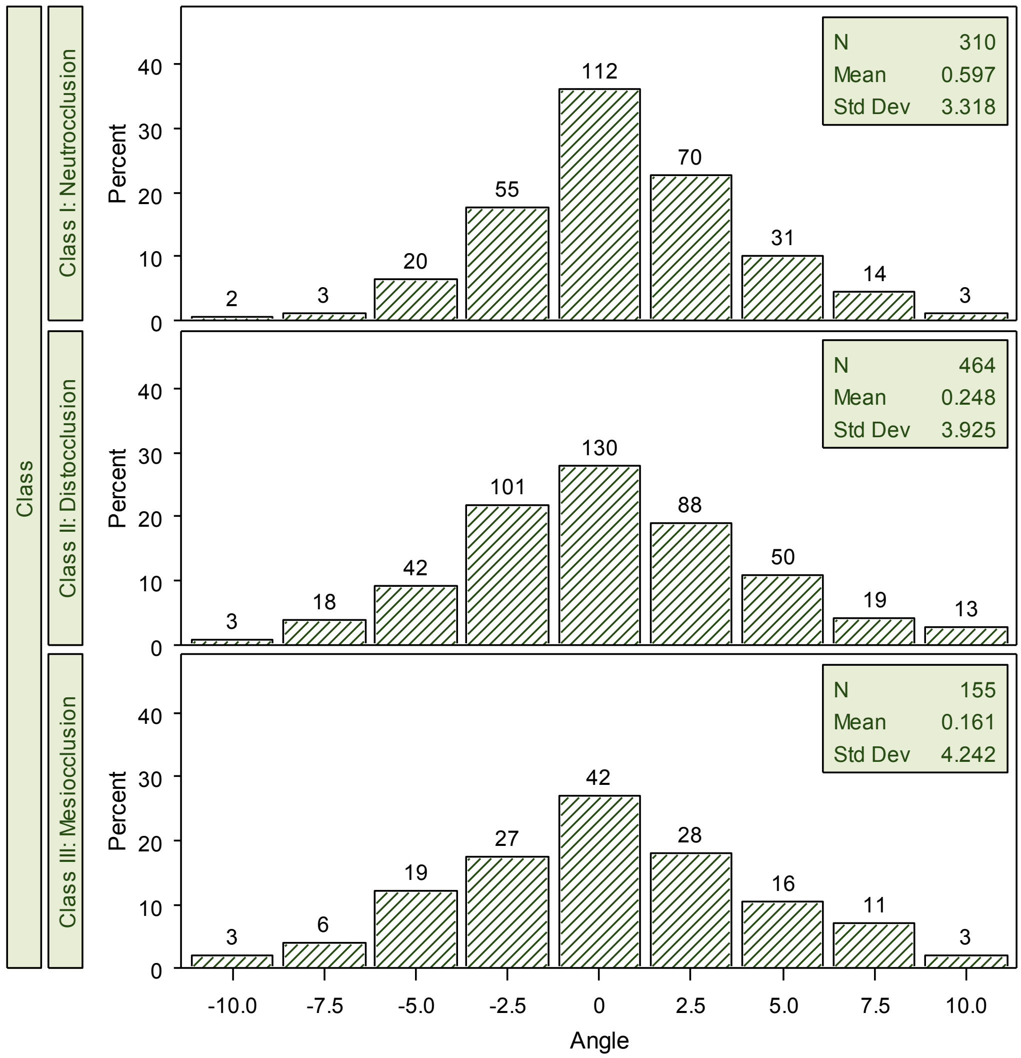


Table of Class by Angle

Class *Frequency* *Row Pct*	*Angle* -10	*-7.5*	*-5*	*-2.5*	*0*	*2.5*	*5*	*7.5*	*10*	*Total*
Class I:	2	3	20	55	112	70	31	14	3	310
Neutrocclusion	0.65	0.97	6.45	17.74	36.13	22.58	10.00	4.52	0.97	
Class II:	3	18	42	101	130	88	50	19	13	464
Distocclusion	0.65	3.88	9.05	21.77	28.02	18.97	10.78	4.09	2.80	
Class III:	3	6	19	27	42	28	16	11	3	155
Mesiocclusion	1.94	3.87	12.26	17.42	27.10	18.06	10.32	7.10	1.94	
Total	8	27	81	183	284	186	97	44	19	929

Statistics for Table of Class by Angle

Statistic	*DF*	*Value*	*Prob*
Chi-Square	16	26.3809	0.0489
Likelihood Ratio Chi-Square	16	26.9511	0.0420
Mantel-Haenszel Chi-Square	1	1.7729	0.1830
Phi Coefficient		0.1685	
Contingency Coefficient		0.1662	
Cramer's V		0.1192	

Sample Size = 929

Table 4 and Figure 10. Frequency distribution of angle choice by skeletal classification.

An exploratory statistical analysis was implemented at the end of the analyses described above to take into consideration the fact that each respondent might have their own bias of preference towards one angle. Therefore, the 30 angles of choice for each subject were grouped and averaged resulting in 31 (N = 31) answers. A chi-square goodness-of-fit test with respect to the null hypothesis that “Status and Mean Angle Choice” were independent was used. Since p=0.5668 (p>.05), we did not reject the null hypothesis. Concluding that orthodontists, orthodontic residents, and lay people have the same distribution of angle of choice. Once again, the 0 degree angle was the most commonly chosen one despite of being an orthodontist, a resident, or a lay person.

3) OHP relationship with FH

Finally, a two one-sided t-test (TOST) equivalence analysis was done to assess the difference between the HC line and FH. The results did not demonstrate any significant differences between the HC line measured on the soft-tissue rendering and FH measured on the lateral cephalometric radiograph generated from the CBCT image in this same orientation (Upper bound t-value = 4.75, $p < 0.003$, Lower bound t-value = -3.89, $p < 0.003$). Since the overall p-value is < 0.003, the null hypothesis that the two measurement methods (soft-tissue HC line and hard-tissue FH) are not equivalent was rejected, concluding in favor of equivalence, defined as the mean deviation being located within our chosen equivalence limits (-.5, .5) in the population represented in this sample as shown in Table 5 and Figure 11.

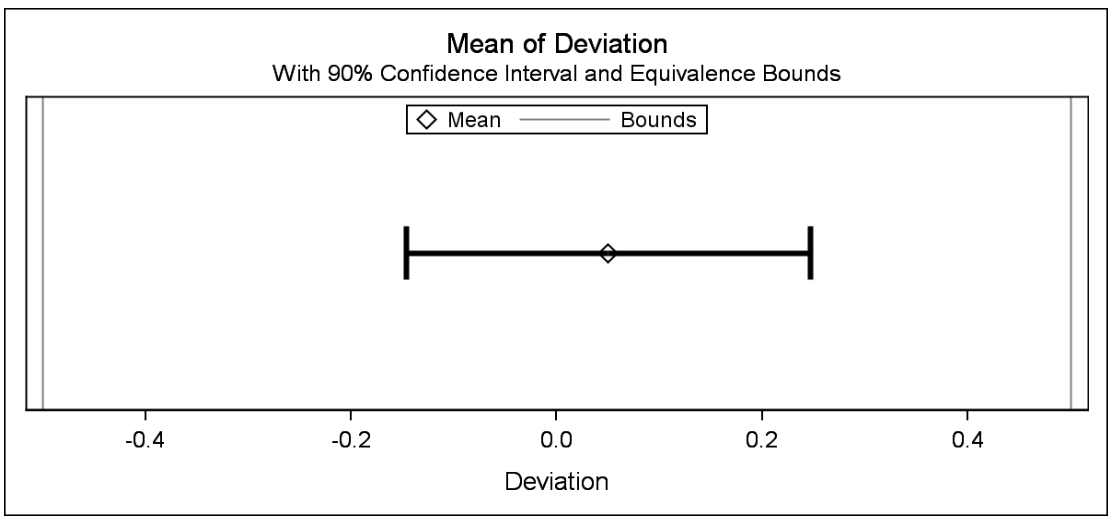
The MEANS Procedure

Analysis Variable : Deviation

N	Mean	Std Dev	Std Error	Lower 90% CL for Mean	Upper 90% CL for Mean	Minimum	Maximum
30	0.0500	0.6340	0.1157	-0.1467	0.2467	-1.3000	1.7000

TOST Level 0.05 Equivalence Analysis

Mean	Lower Bound		90% CL	Mean		Upper Bound	Assessment
0.0500	-0.5	<	-0.1467	0.2467	<	0.5	Equivalent



Test	*Null*	*DF*	*t Value*	*P-Value*
Upper	-0.5	29	4.75	<0.0001
Lower	0.5	29	-3.89	0.0003
Overall				0.0003

Table 5 and Figure 11. Deviations between soft-tissue HC line and hard tissue FH measures.

Discussion

1) Most pleasant head position – general

Every subject was asked to identify one specific head position as the most pleasant for each of the 30 models. This position most often ($p < 0.05$, SD = 2.5°) turned out to be the one where FH was parallel to the floor and was named: Optimal Head Position (OHP). Based on this most pleasant position, a soft-tissue reference line was created using HC landmarks, which are compatible with FH. Orthodontists, on average, tended to prefer the head tilted slightly down (Mean = -0.250), whereas residents and lay people preferred the head with a slight upward tilt (Mean = 0.40 and 0.84, respectively). These differences were not statistically significant.

Since orthodontists rely on the proper location of cephalometric landmarks and their angular as well as linear relationships, it is imperative that the patient's head position be easy to locate and not dependent on the patient's proprioception.

Another problem with having the patient determine his or her own head position is the fact that people habitually carry their heads to their best comfort.

Some notable figures in history illustrate this well: Princess Diana was notorious for her downward-gazing head posture. Conversely, the famous author William F. Buckley Jr. tended to carry his head tilted skyward. We must question if it is appropriate to consider treating a patient for greater proclination of the incisors or advancement of Pogonion for a patient like Princess Diana, or to claim better esthetics with greater protrusion of the mandible for a patient similar to William F. Buckley Jr.

Furthermore, another reason for supporting the OHP advocated here is based on the fact it is an operator-defined position. Once Helion to Canthion line is mentally visualized on the patient's profile, it is easy for the operator to position the patient's head with this mental line parallel to the floor.

Unfortunately, this study did not evaluate the reproducibility of OHP. A future study will ask for different subjects to choose the most pleasant over time and verify if they are selecting OHP repeatedly.

2) Most pleasant head position – according to skeletal classification

Regardless of the skeletal classification of the patient, the majority of the subjects (within one standard deviation) thought one specific position was the most pleasant - OHP.

This study demonstrated that there is no statistically significant difference in the subject's preferred head orientation regardless of skeletal classification. It would seem logical that a patient with a class III skeletal relationship demonstrating a characteristic protrusive lower jaw relative to the upper jaw might appear more pleasant with his or her head tilted down relative to the average face in OHP in order to reduce the display of the mandibular chin prominence. This, of course, would tend to change the appearance of other facial characteristics such as the tip of the nose, the upper lips, slant of the eyes and zygoma, to name a few.

Conversely, at the other end of the spectrum, patients with a class II skeletal jaw discrepancy would ideally want to maximize the prominence of the chin, as the mandible appears retruded juxtaposed with the maxilla. Adjusting the head position to enhance the appearance of the mandible would have a corresponding upward tilt to the other facial features.

All of this considered, this research shows that the subjects chose the head orientation, on average, coincident with the HC line parallel to the edge of the film and therefore, to the floor, regardless of the skeletal classification of the model. This hints at a universality amongst skeletal classifications that suggests that this head position can be used regardless of whether the maxilla appears retruded or protruded; or the mandible relatively advanced or set back. Future studies should be designed to test universality. Figure 13 shows an example of soft-tissue profile renderings for a class I, class II, and class III patient oriented in OHP, respectively.

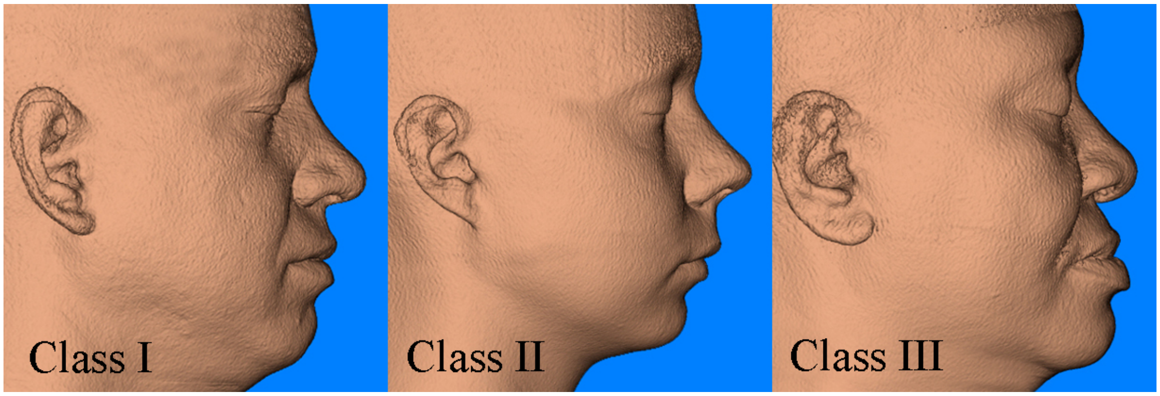


Figure 12. Three soft-tissue CBCT renderings for patients of varying skeletal classifications: 1) Class I, 2) Class II, 3) Class III, aligned to OHP.

3) OHP relationship with FH

When SN line is used as a reference horizontal line, one may wrongfully diagnose soft and hard-tissue relationships because it is dependent on the anatomy of the cranial base. For instance, Bjork's[34] studies of facial growth demonstrated a significant difference between reference FH and SN. He illustrated that two individuals with near identical profiles had large variations in skeletal measurements of mandibular prognathism. Subjects with a steep cranial base angle who were considered to have orthognathic profiles were viewed as having prognathism in NHP or when FH was positioned parallel to the floor. Hence, he advocated the use of FH rather than SN.

A similar phenomenon has been observed in the soft-tissue analysis when comparing NHP to OHP. Figure 14 illustrates two patients whose photographs were originally taken in NHP and were later rotated using Adobe Photoshop software (version 12.0.4, San Jose, CA) to have the HC line parallel to the inferior edge of the image. Red lines were utilized to connect the points Helion and Canthion to form the HC line. When this is set parallel to the floor, OHP is obtained. It is important to note the effect that this orientation has on the appearance of the relative retrognathism or prognathism of the mandible. In the first patient, she appears more retrognathic in NHP and less retrognathic when oriented to OHP. The second patient appears more prognathic in NHP and less prognathic in OHP. This infers that the visual aid in diagnosing the appearance of the soft-tissue and jaw relationships can be influenced by the orientation of the head.

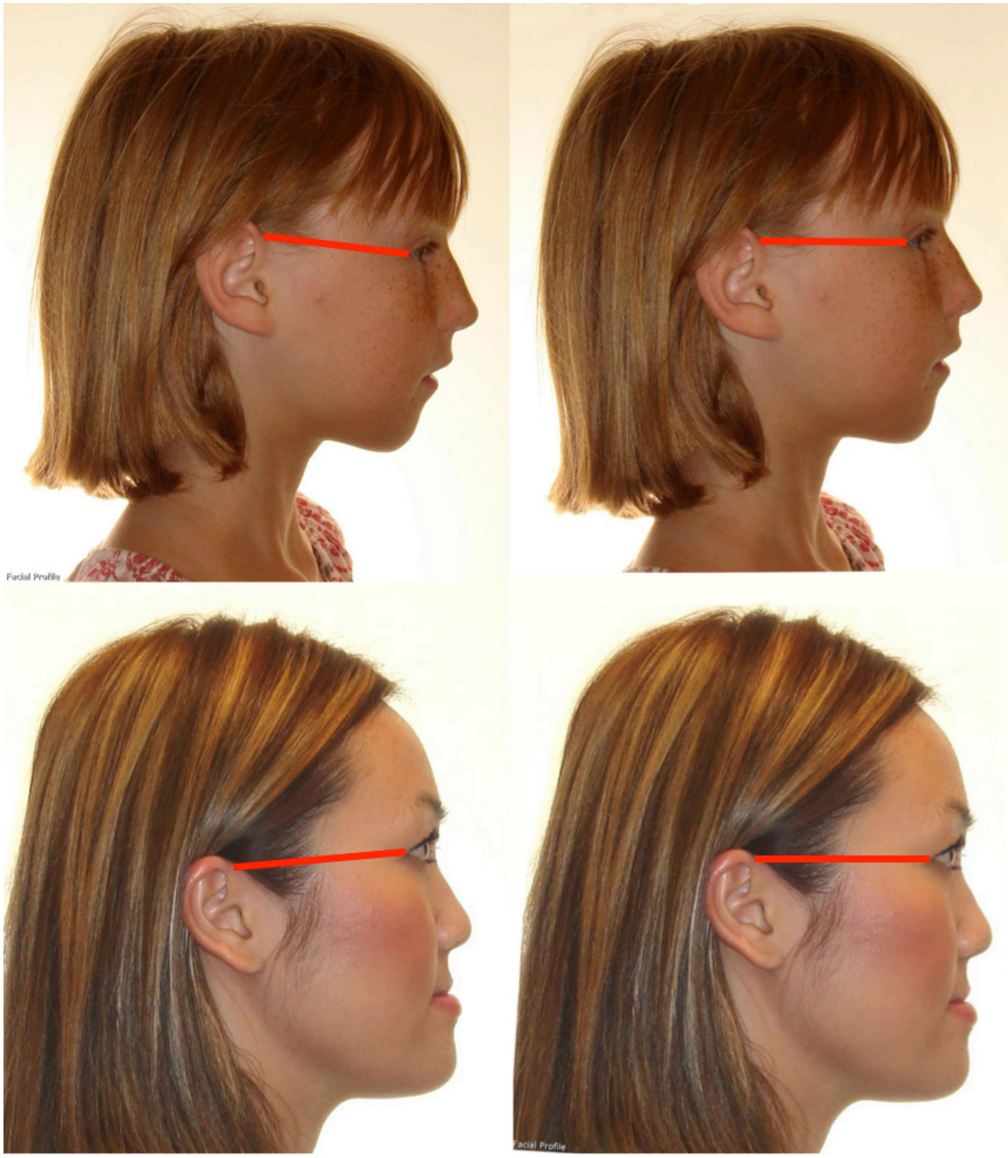


Figure 13. Natural Head Positions (left) and Optimal Head Positions (right) for two patients undergoing initial orthodontic records. Red lines connect points Helion and Canthion are used to reorient the extra-oral images to OHP by setting them parallel to the floor.

Since it has been demonstrated that OHP is parallel to FH, aligning all extra-oral pictures, hard-tissue cephalograms, and soft-tissue CBCT renderings is easier and can be easily related to a true vertical line perpendicular to it. In addition, it can be reasoned that it may have greater accuracy in reproducibility since distinct anatomical points will be chosen rather than a patient's subjective position of the head.

At least one current computerized cephalometric analysis relies on an average distance from glabella to orient its vertical reference plane, which belies the concept of a true vertical line being unique to each person. In the Dolphin Imaging software (version 11.5, Chatsworth, CA), the true vertical line (TVL) that is used as reference for soft-tissue norms is set with its most superior point as an arbitrary 8.5 mm anterior to glabella. Based on the head tilt of the patient, the accuracy of TVL is suspect. By orienting the head to OHP, a vertical line can be used perpendicular to HC line to make quantitative measurements for the soft-tissue, since orientation of the patient into OHP concurrently orients him or her into FH.

Ideally, patients and treating orthodontists may benefit from a head orientation defined by the operator, i.e. reproducible over time that is parallel with FH. The easily located, definite landmarks Helion and Canthion used to orient the head into OHP will offset the subtle variations in head position seen in NHP.

When adjusting the patient's position prior to taking a profile photograph or cephalogram (or orienting a lateral cephalogram extracted from a CBCT image), one has to rely on soft-tissue landmarks. After the radiographic image has been obtained, in order to have FH parallel to the floor, one has to simply tilt the film. However, locating the cephalometric landmarks of Porion and Orbitale might insert critical error to this method. One of the criticisms for using FH as a reference in cephalometric analysis is the inter-operator variability in determining the landmarks.[6,13,15] Since the advent of Cone Beam Computed Tomography, there has been increased accuracy in placing cephalometric landmarks, most notably the point Porion which is used to determine FH.[4,18,19,21,22]

During cephalometric tracing, setting FH parallel with the inferior edge of the image concurrently orients the image of the patient in OHP. This would be of benefit in that it offsets deviations in head placement during the CBCT imaging scan, allows a greater range of acceptance for vertical deviations in head position when scanning patients thus radiation exposure can be reduced by requiring fewer remakes, orients the cephalogram consistent with the horizontal position of the patient's head, increases accuracy of soft-tissue analysis by having a consistent reference point, and all is consistent with extra oral photographs taken in OHP. This parallelism suggests that cephalometric films could be routinely oriented to FH; CBCT volume projections could be oriented to HC; photographs could be oriented to HC, and all would be compatible with any soft-tissue measurements based on a true vertical line.

It has been suggested in the literature by Ricketts[10] that a soft-tissue line from the ear tragus to the soft-tissue orbit can be useful for clinical visualization. (Figure 15) However, this is at best an estimate of where the true FH is on the hard-tissue. The ear tragus may not correlate exactly with the internal auditory meatus and the soft-tissue orbit is certainly variable, as it is not clearly demarcated on the face of the patient. OHP can be suggested as an improvement over soft-tissue estimations of FH that can be clinically useful for relating the soft-tissue to the hard-tissue.

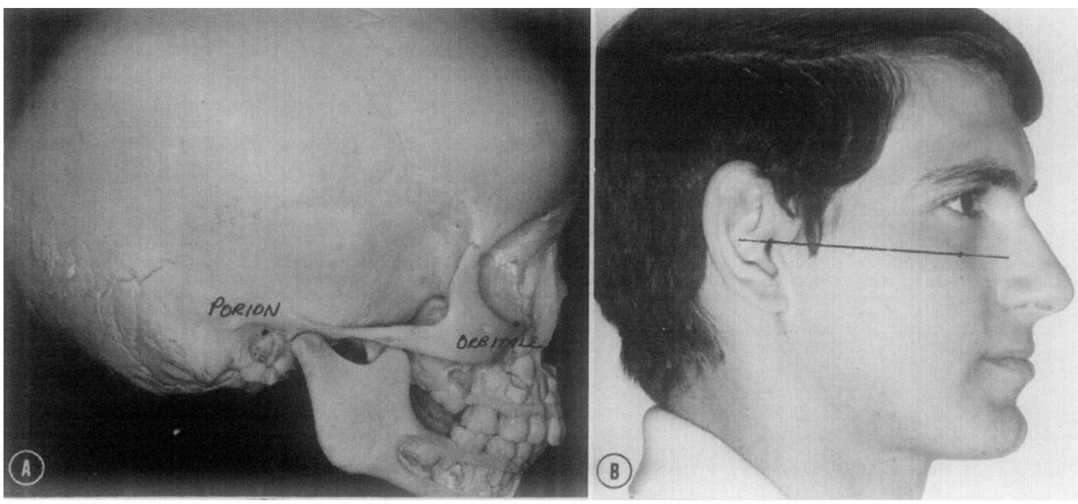


Figure 14. Soft-tissue orientation of the head to approximate FH, as suggested by Ricketts[12]. (Reprinted from Ricketts RM, Schulhof RJ, Bagha L. Orientation sella-nasion or frankfort horizontal. *Am J Orthod*. 1976;69(6):648-654. With permission from Elsevier.)

Arnett[1,2] illustrates in his facial keys to orthodontic diagnosis and treatment planning that the FH parallel to the floor should not dictate head posture used for treatment planning. He claims that the esthetic appearance on the cephalogram will not translate to the patient’s head posture.[1] In disagreement with this statement, this study shows that orthodontists, residents, and staff all preferred the head orientation that was consistent with the HC line parallel to the inferior edge of the image, and thus also with FH parallel to the inferior edge of the frame since the evidence in this study suggests these lines coincide with one another.

In accordance with the work of Moorrees and Luthy,[3,10] we found supporting evidence to reinforce their statement that “FH is the best known and most acceptable approximation of the physiologic horizontal allowing one to view the greatest differences in facial soft-tissue between racial groups within minimal variation between the groups.” (p. 213). Barbera[5] demonstrated in his research that four planes, the neutral horizontal axis, FH, Krogman-Walker Line, and palatal plane demonstrated near parallelism. He also mentioned the FH angulation is subject to landmark identification error.[5] Using the points Helion and Canthion to construct the HC line may improve the accuracy in orientation of the head when FH is difficult to locate as our findings suggests that they are parallel.

The disadvantage of OHP at this point is that it is a new concept and there is no current research to support it. This study offers the first insight into this new orientation of the head. Although the landmarks Helion and Canthion appear to be straightforward to locate, we are uncertain how the ear insertion point and lateral canthus changes with time or how it continues to correlate with Porion. It is possible, with continued ear growth throughout life, Helion may change. The outer canthus may develop a slightly different location throughout time due to the increasing elasticity of the skin with age which may change the reliability of point Canthion.

The ultimate goal of this study was to create an operator-defined head position based on clearly identifiable soft-tissue landmarks because the correct diagnosis of soft-tissue relationships is critical for optimal treatment planning. After all, orthodontists treat faces, not only teeth.

Conclusions

As a result of this study, it can be concluded that: (1) there is a soft-tissue reference line to orient the head based on two landmarks, Helion and Canthion, in a horizontal dimension that can be easily and clearly located; (2) this position is deemed the most pleasant, (3) it applies regardless of skeletal classification, and (4) it is parallel to the floor and to FH.

OHP with HC line parallel to the floor is an esthetically pleasing and reproducible soft-tissue head orientation that can be confidently and meaningfully used in contemporary cephalometric analyses based on a CBCT scan's volume projection to measure both hard and soft-tissues in relation to a vertical reference line drawn parallel to the edge of the frame. Furthermore, if a plain film is used or if the CBCT volume projection is not utilized to orient the head position, then FH may be positioned parallel to the floor and similar reliability may be obtained.

Thus, during diagnosis and treatment planning, OHP may be considered as an operator-defined improvement on NHP that adds increased confidence and insight to contemporary cephalometric analyses and treatment recommendations. Future studies would be beneficial to evaluate the use of OHP in clinical practice. Suggested future studies include: (1) the use of perceptometrics software to determine the most pleasant head orientation by allowing the subject to rotate the model's head into the orientation that he or she feels is best; (2) comparison studies of NHP to OHP; (3) reliability testing of OHP; (3) testing the relationship of OHP to a true vertical line; (4) testing accuracy with repeated recordings of OHP; (5) reproducibility testing of OHP; (6) evaluating the relationship of Helion-Porion and Canthion-Orbitale; (7) landmark identification error when locating Helion and Canthion, (8) universality testing of OHP; (9) repeat the current study design but recruit true lay persons; (10) assessing the adequacy of HC line as a reference plane when making a facebow transfer as compared to the traditional infraorbital pointer and palpation; and (11) assessing acceptance of OHP in clinical practice and long-term evaluation of its effectiveness in diagnosis and treatment planning.

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