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Head Orientation in CBCT-generated Cephalograms

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Abstract

Objective—To determine the reliability of obtaining two-dimensional cephalometric measurements using two virtual head orientations from cone-beam computed tomography (CBCT) models.

Materials and Methods—CBCT scans of 12 patients (6 class II and 6 class III) were randomly selected from a pool of 159 patients. An orthodontist, a dental radiologist, and a third-year dental student independently oriented CBCT three-dimensional (3D) renderings in either visual natural head position (simulated NHP) or 3D intracranial reference planes (3D IRP). Each observer created and digitized four CBCT-generated lateral cephalograms per patient, two using simulated NHP and two using 3D IRP at intervals of at least 3 days. Mixed-effects analysis of variance was used to calculate intraclass correlation coefficients (ICCs) and to test the difference between the orientations for each measure.

Results—ICC indicated good reliability both within each head orientation and between orientations. Of the 50 measurements, the reliability coefficients were ≥0.9 for 45 measurements obtained with 3D IRP orientation and 36 measurements with simulated NHP. The difference in mean values of the two orientations exceeded 2 mm or 2° for 14 (28%) of the measurements.

Conclusions—The reliability of both virtual head orientations was acceptable, although the percentage of measurements with ICC >0.9 was greater for 3D IRP. This may reflect the ease of using the guide planes to position the head in the 3D IRP during the simulation process.

Keywords

Head orientation; CBCT cephalograms

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INTRODUCTION

The selection of head orientation is as important when measuring distances and angles on lateral cephalograms from cone-beam computed tomography (CBCT) images as it is in conventional cephalometry. Many cephalometric landmarks in two-dimensional (2D) projected images are defined by a geometric property, and the location will vary depending on the head orientation.[1–3] For example, Menton is commonly defined as the most inferior point on the chin, and this location varies with different head orientations. Different head orientations affect the positions of all the orientation-dependent landmarks.[4,5]

Natural head position (NHP) has been described as the most rational physiologic and anatomic orientation for evaluating the face, jaws, and teeth.[2,6–10] Visual, somatosensory, and proprioceptive reflexes integrated with vestibular reflexes ensure the postural stability[11] that should produce reproducible cephalograms using the line of vision as an extracranial reference. However, in conventional cephalometric x-rays, the use of cephalostat, chain, mirror, and a system of instruments for measuring and recording head orientation have been proposed to better reproduce NHP.[12,13] If NHP is the head orientation of choice to generate cephalograms from CBCTs, the use of CBCT-generated cephalograms requires investigation of how to record NHP during CBCT acquisition or how to simulate NHP after CBCT acquisition.

During CBCT acquisition, no cephalostat or three-dimenional (3D) inclinometer has been introduced to date that would standardize the 3D head orientation and record head pitch, roll, and yaw in NHP during the acquisition of 3D images. Patient head orientation varies from lying down, to sitting, to standing depending on the CBCT scanner used.[14,15] After CBCT acquisition, head rotation or tilt can be corrected to simulate NHP using currently available image analysis software, but any extracranial reference that might be used during acquisition is not transferred to the head volume of the 3D-rendered visualization.

2D intracranial reference lines operationally defined by landmarks, such as the Frankfort horizontal or S-N line, are also commonly used in conventional cephalometry, but 2D intracranial reference lines exhibit considerable variability for longitudinal assessments.[4,6,9,16] Preliminary studies by Kumar and Ludlow[17] have tested six different orientations of a phantom before generating the cephalograms and did not observe statistically different measurements for the different orientations. But the geometry of the phantom, which consisted of perpendicular plexiglass rods with a brass rod on the ends, cannot be compared to the complex craniofacial morphology of human patients. The purpose of this study was to determine the reliability and systematic differences of cephalometric measurements when calculated using two virtual intracranial head orientations after CBCT acquisition: visual axis natural head position (simulated NHP) and 3D intracranial reference planes (3D IRP).

MATERIALS AND METHODS

Presurgery CBCTs of 12 patients (6 skeletal class II and 6 skeletal class III) were randomly selected within their skeletal group to represent the spectrum of diverse skeletal problems from a pool of 159 orthognathic surgery patients. Biomedical Institutional Review Board approval was obtained, and informed consent and Health Insurance Portability and Accountability Act (HIPAA) authorization forms were signed by all subjects.

The CBCT scans were obtained by NewTom 3G (QR-NIM s.r.l., Verona, Italy) using a 12-inch field of view. The volumetric data were reconstructed with 0.3 × 0.3 × 0.36 mm voxels and 460 slices. The volume data were exported in DICOM format into Dolphin Imaging software (version 10.5, Dolphin Imaging & Management Systems, Chatsworth, Calif). Both soft- and hard-tissue 3D renderings from CBCT scans were created and oriented in either the visual axis simulated NHP (Figure 1) or 3D IRPs (Figure 2). The extracranial reference line that defines NHP is based on the true horizontal that depicts the subject looking at a distant point at eye level. The simulated NHP orientation was achieved without using any guide planes, but rather by using each observer's subjective interpretation of the plane of vision to best define the true horizontal plane. The 3D IRP orientation was achieved using three planes defined by at least three landmarks or two landmarks and a plane: Frankfurt horizontal, midsagittal, and transporionic planes. The Frankfurt horizontal plane was defined bilaterally by the right and left porion and right and left orbitale landmarks. The midsagittal plane was defined by nasion (Na), anterior nasal spine (ANS), and basion landmarks. The transporionic plane was defined bilaterally by porion landmarks and perpendicular to the Frankfurt horizontal plane. In the sagittal, axial, and coronal views, the volume was rotated until the Frankfurt plane was oriented horizontally, and the midsagittal and transporionic planes were oriented vertically.[18]

Three observers, an orthodontist, a dental radiologist, and a third-year dental student, were calibrated for the head orientation procedures using 10 images not included in this sample.[19] Working independently after calibration, each observer generated four lateral cephalograms from each CBCT in perspective projection: two using simulated NHP and two using 3D IRP head orientation (Figure 3). The segmentation parameters for each scan were annotated by each observer and used for all repeated head orientations. An interval of at least 3 days occurred between generation of each 2D cephalogram. Linear and angular measurements commonly used in conventional cephalometric analyses[20] were calculated using Dolphin software (Table 1).

To assess the concordance within and between head orientations, a three-way mixed-effects model with patient (12 levels), orientation (2 levels), and observer (3 levels) as main effects, all pairwise interactions and the three-way interaction were fit for each measurement. Intraclass correlation coefficients (ICCs) within and between orientations were determined using the table of expected mean squares.[21] To test whether there was systematic bias in the orientation effect, a reduced mixed-effects analysis of variance model was fit without the interaction between patient and orientation or the three-way interaction between patient, orientation, and observer. In this reduced model, an F test was calculated for each measurement. The level of significance was set at .05.

RESULTS

The ICCs indicated acceptable to excellent intraand interhead orientation reliability using the 3D IRPs and simulated NHP (Table 1 and Table 2). The ICC was ≥0.90 for 90% of the measurements obtained with 3D IRP orientation and 72% with simulated NHP. The simulated NHP concordance was <0.75 for three measurements: Co-ANS (ICC = 0.74), Na-ANS (ICC = 0.71) and FH-SN (ICC = 0.71). The interhead orientation ICC was >0.90 for 46% of the measurements. Eight (16%) of the measurements had between-head orientation ICCs between 0.62 and 0.75: A to N vertical, A to N perpendicular, maxillary unit length, upper face height, FH-SN, U1-PP, soft tissue N vertical to lower lip, soft tissue N perpendicular to upper lip (Table 1 and Table 2).

The interobserver reliability is shown in Table 1. The ICC was ≥0.9 for 37 (74%) of the interobserver assessments and ≥0.75 for all measurements.

The mean differences between head orientations, controlling for observer and patient are categorized in Table 3. The mean differences between simulated NHP and 3D IRP were ≥2° for 25% of the 16 angular measurements and ≥2 mm for 29% of the 34 linear measurements. Statistically significant ($P < .05$) systematic differences between the two head orientations were indicated for 9 of the 50 measurements (Table 4). Three of these nine measurements were angular measurements, FMA, SNB, and Sn-GoGn. The other six were linear measurements relative to the “true vertical line” as identified in the cephalograms generated from CBCT: A point to N vertical, B point to N vertical, Pg to N vertical, soft tissue N vertical to upper lip, soft tissue N vertical to lower lip, soft tissue N to soft tissue Pg.

DISCUSSION

2D cephalograms can be accurately generated using available commercial software from CBCT 3D images. [22–27] Farman and Scarfe[22] have described methods for creating 2D cephalograms from CBCT volumetric data sets, and Kumar et al[23,24] concluded that both perspective and orthogonal synthesized CBCT projections reproduce conventional cephalograms with similar accuracy compared to skull measurements. However, Kumar et al[23,24] used the head orientation in the conventional cephalogram to guide orientation of the 3D rendered volumes for generating the CBCT cephalograms. The reliability of orientation of the head before the generation of the 2D cephalogram from CBCT and systematic differences in commonly used linear and angular measures between the orientations have not been studied. The findings in this study indicate acceptable to excellent intra- and interhead orientation reliability using both the 3D IIRP and simulated NHP, but 3D IRP showed a higher percentage of excellent reliability.

Although the three observers in this study had different training backgrounds, the interobserver reliability was good to excellent for all measurements and head orientations. This minimal effect of prior experience can be explained by careful observer calibration with the definition of the 3D IRP and simulated NHP before the start of this study, using a set of 10 CBCT scans not included in this study.

Mean differences between the simulated NHP and 3D IRP head orientations (>2° for 4 of the 16 angular measurements and >2 mm for 10 of the 34 linear measurements) suggested that head orientation not only affected measurements relative to reference lines, but also the relative location of anatomic landmarks. Differences in diagnostic measurements depending on head orientation can be clinically significant and can affect treatment planning.[28,29] Nine of 50 measurements showed statistically significant difference between head orientations ($P < .05$). All six statistically significant linear measurement differences between the visual axis NHP and 3D IRP were relative to the interpreted true vertical line. This can be explained by differences between the determination of the true vertical when NHP and IRP head orientation are used (Figure 4).

The results of this study showed that both simulated NHP and 3D IRP before generation of 2D cephalograms provide acceptable to excellent reliability for measurements obtained from CBCT-generated lateral cephalograms. These results cannot be directly compared with previous findings for conventional 2D cephalograms.[2–10] The standard deviation of 2D intracranial cephalometric reference lines (eg, Frankfort, palatal, SN) to the true vertical and to each other has been reported to be 5° to 7° [3,6,9,10] with a variance of 25° to 36° (SD).[2] The 3D IRP in this study used all three planes of space: Frankfurt horizontal, midsagittal, and transporionic planes. 3D CBCT imaging allows visualization of anatomic relationships that are impossible to discern in 2D cephalometry.

Although NHP has been shown to be reproducible in 2D cephalometry, the slightly higher proportion of ICC ≥0.90 for 3D IRP compared with simulated NHP in this study can be explained by the use of 3D intracranial reference planes directly in the 3D hard tissue rendering and difficulties in simulating NHP after CBCT acquisition. Three main difficulties exist in determining NHP using CBCTs. First, currently it is only possible to determine a simulated NHP after CBCT acquisition, because no 3D inclinometer has been introduced to record head orientation relative to extracranial references during CBCT acquisition. Second, observers orient the 3D head soft tissue rendering presuming that the subject is looking at a point at eye level in order to define the true horizontal plane, without any reference or guide planes. Third, previous studies that reported high reproducibility of NHP have only measured sagittal (lateral) 2D projections.[2–10,13] As Ackerman et al[30] emphasized, CBCT imaging reveals the need to record head orientation in all 3 planes of space to assess pitch, roll, and yaw.

Unless it is possible to standardize NHP, 3D IRP aids head orientation in CBCT imaging. The use of inclinometers in 2D cephalometry to transfer a predetermined head position to the cephalostat have aided reproducibility of NHP.[13] The findings from this study suggest that future studies are needed to investigate the use of a 3D orientation sensor to standardize NHP in CBCT imaging.

CONCLUSIONS

- Simulated NHP and 3D IRP head orientation of CBCT images provide acceptable to excellent reliability of measurements obtained from CBCT-generated lateral cephalograms.
- 3D IRP was slightly more reliable with a higher proportion of ICC $\geq$0.90, possibly because of the use of 3D intracranial reference planes to aid reproducibility of orientation.
- Significantly different measurements between the two head orientations suggest that orientation of the head in CBCT images may not only affect the reliability of the measurements but also the relative location of anatomy and therefore, diagnosis and treatment planning. Future studies are need to aid standardization of NHP for CBCT acquisitions.

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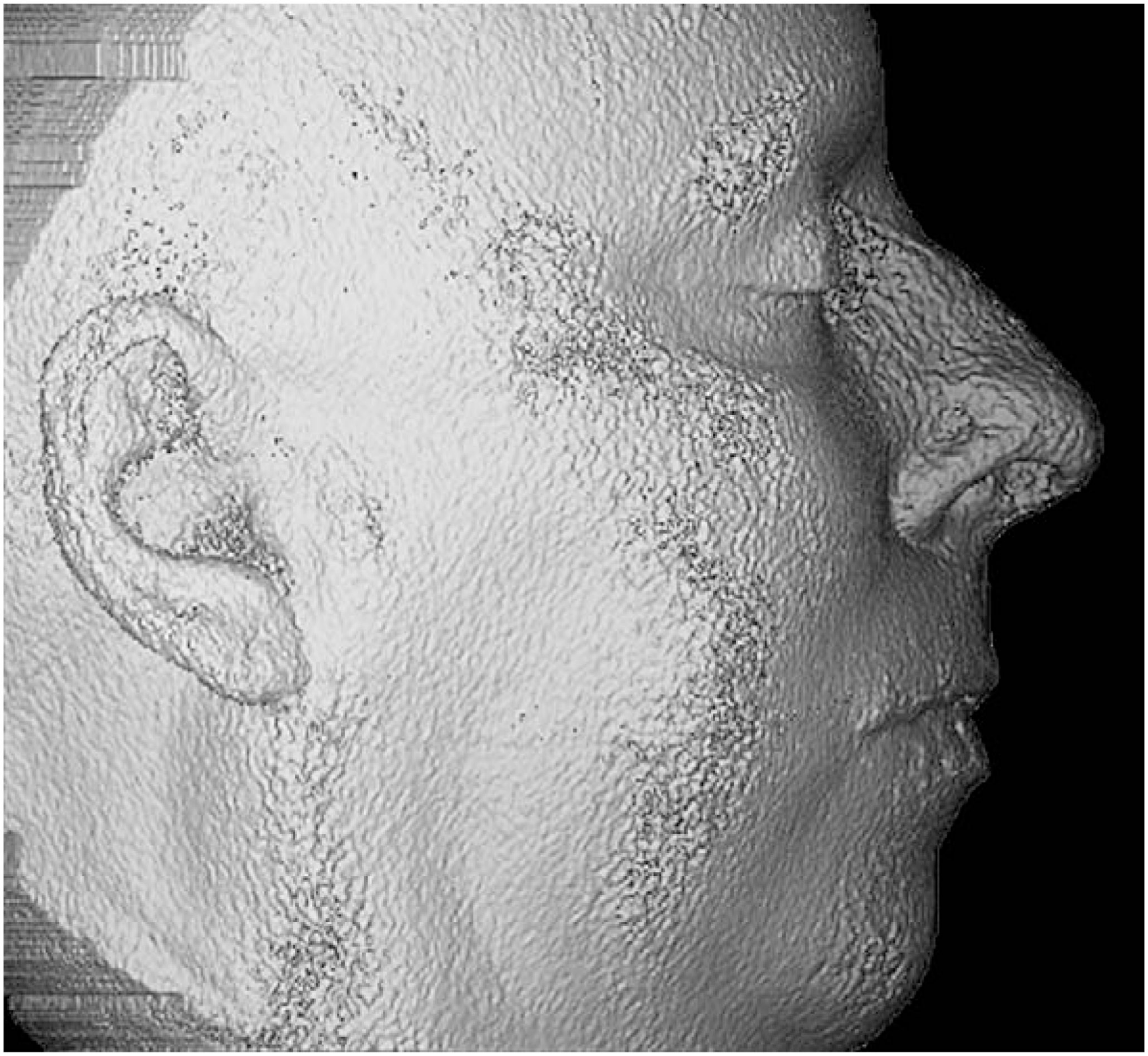

Figure 1.
3D soft tissue rendering oriented in NHP used to build the 2D lateral cephalogram in perspective projection.

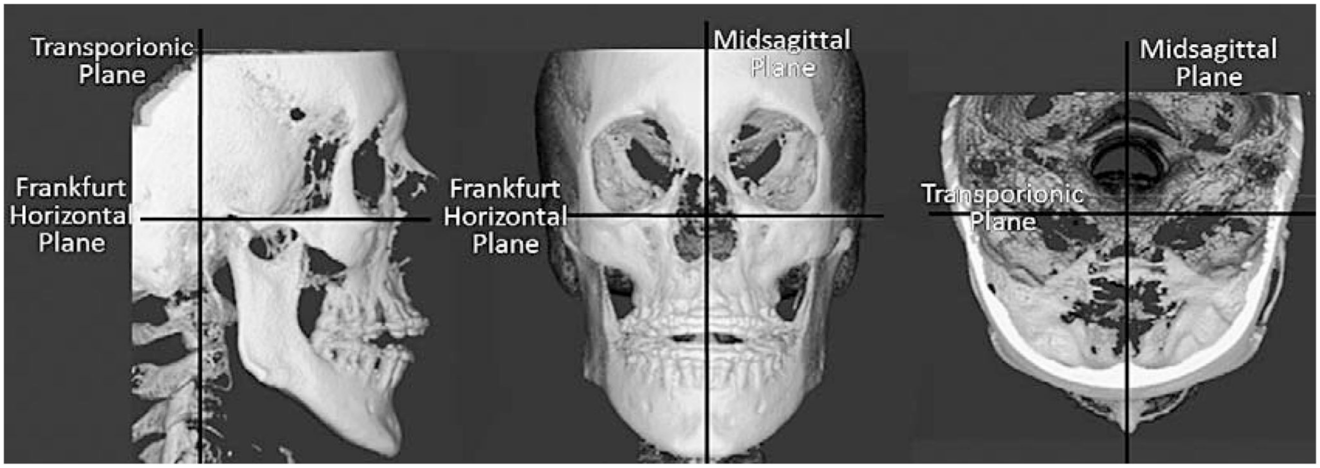

Figure 2.
3D hard-tissue rendering oriented using intracranial reference planes to generate the 2D lateral cephalogram in perspective projection (soft tissue set to transparent for visualization purposes).

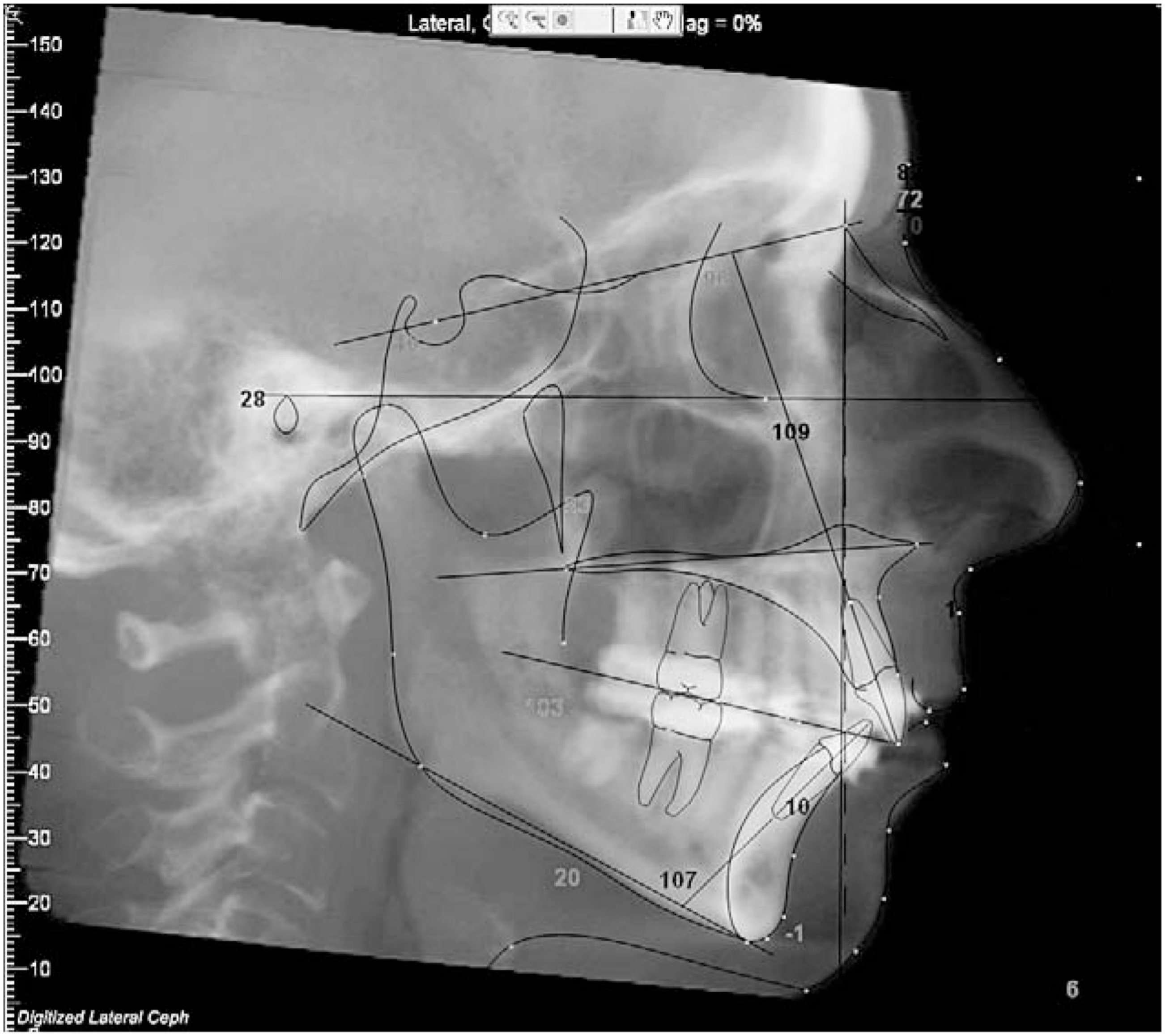

Figure 3.
2D lateral cephalogram generated from the 3D rendering with the head oriented using FH.

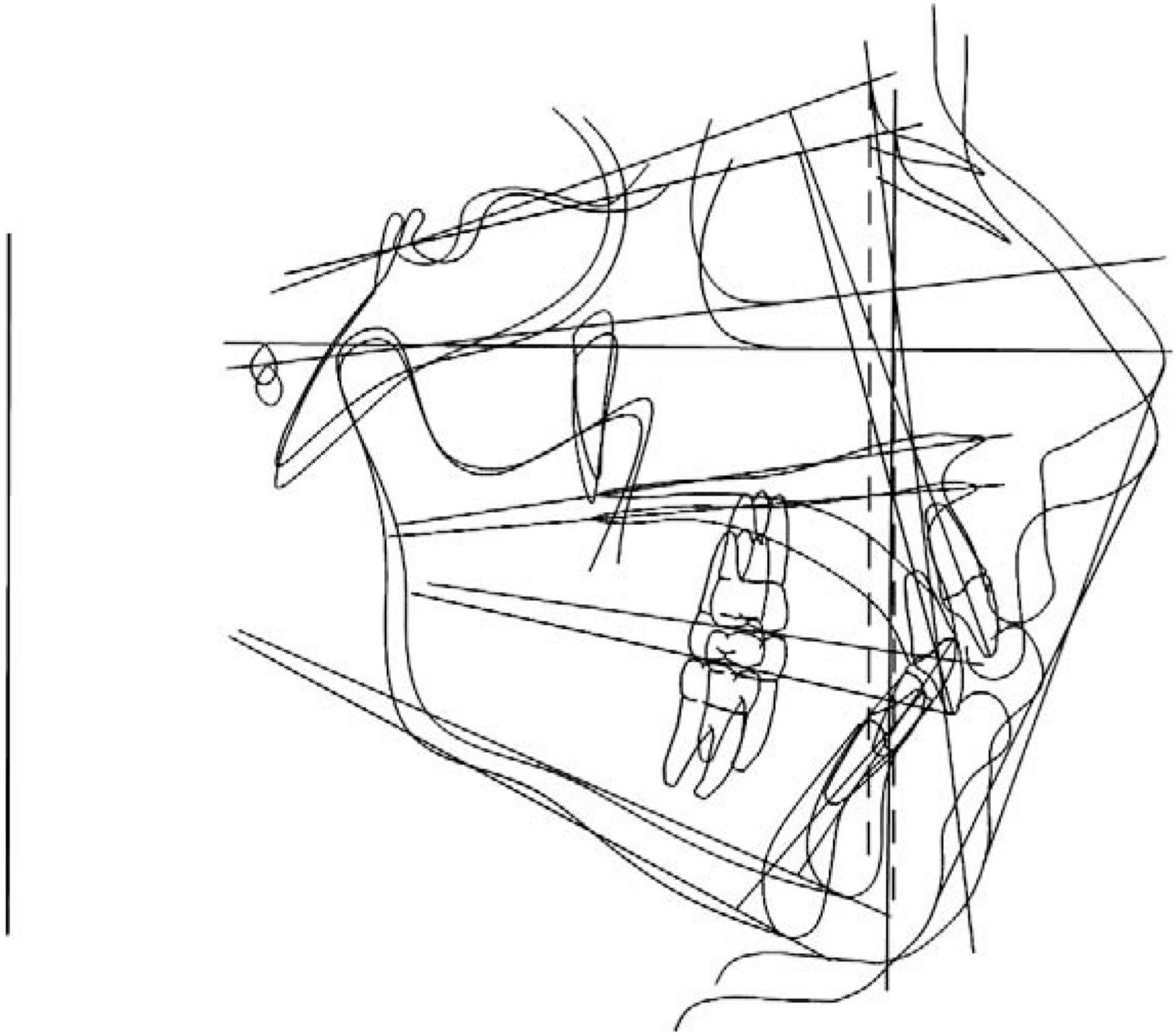

Figure 4.
Superimposition at true vertical (vertical line at far left) of cephalometric tracings generated IRP/NHP for a patient to illustrate the effect of head orientation on angulation of anatomic planes and relative location of anatomy.

Table 1

Intraclass Correlations of the Cephalometric Measurements Assessed

	Measurements			
Skeletal AP	**3D IRPs**	**Simulated NHP**	**Between-Head Orientations**	**Interobserver Reliability**
SNA (°)	0.94	0.85	0.83	0.89
SNB (°)	0.99	0.96	0.95	0.98
ANB (°)	0.99	0.99	0.97	0.99
A to N vertical (true vertical) (mm)	0.89	0.92	0.73	0.85
B to N vert (true vertical) (mm)	0.95	0.96	0.79	0.89
Pg to N vertical (true vertical) (mm)	0.95	0.97	0.79	0.89
A-N perpendicular (mm)	0.89	0.84	0.75	0.88
B-N perpendicular (mm)	0.96	0.98	0.93	0.97
Pog-N perpendicular (mm)	0.96	0.98	0.92	0.97
Maxillary unit length (Co-ANS) (mm)	0.96	0.74	0.75	0.89
Mandibular unit length (Co-Gn) (mm)	0.99	0.92	0.89	0.97
Maxillary/Mandibular difference (Co-Gn – Co-ANS) (mm)	0.99	0.98	0.97	0.99
Dental AP				
U1-SN (°)	0.96	0.89	0.86	0.94
U1-NA (°)	0.96	0.89	0.84	0.94
U1-NA (mm)	0.92	0.83	0.78	0.90
U1 FH (°)	0.93	0.89	0.79	0.92
IMPA (L1-MP) (°)	0.96	0.96	0.94	0.96
L1-NB (°)	0.97	0.95	0.94	0.96
L1-NB (mm)	0.98	0.95	0.95	0.96
L1 protrusion (L1-Apo) (mm)	0.98	0.95	0.95	0.96
L1 to A-Po (°)	0.92	0.91	0.89	0.90
Wits Appraisal (mm)	0.99	0.99	0.98	0.99
Interincisal angle (U1-L1) (°)	0.89	0.86	0.84	0.87
Overjet (mm)	0.99	0.98	0.98	0.99
Pog-NB (mm)	0.99	0.96	0.93	0.98
FMIA (L1-FH) (°)	0.97	0.97	0.95	0.96
Skeletal vertical				
Total anterior face height (N-Me) (mm)	0.99	0.87	0.82	0.95
Upper face height (N-ANS) (mm)	0.87	0.71	0.62	0.77
Lower face height (ANS-Me) (mm)	0.99	0.91	0.87	0.96
Nasal height (%)	0.92	0.9	0.84	0.89
Post facial height (Co-Gn) (mm)	0.97	0.92	0.90	0.94
PFH:AFH (%)	0.95	0.92	0.88	0.92
FMA (MP-FH) (°)	0.99	0.97	0.94	0.98
SN-GoGn (°)	0.98	0.93	0.92	0.95
Occ plane to SN (°)	0.99	0.93	0.91	0.96
Occ Plane to FH (°)	0.97	0.96	0.90	0.96

	Measurements			
Skeletal AP	**3D IRPs**	**Simulated NHP**	**Between-Head Orientations**	**Interobserver Reliability**
FH-SN (°)	0.9	0.71	0.71	0.78
Dental vertical				
U1-PP (UADH) (mm)	0.92	0.83	0.74	0.90
L1-MP (LADH) (mm)	0.99	0.85	0.82	0.94
U6-PP (UPDH) (mm)	0.95	0.93	0.87	0.94
L6-MP (LPDH) (mm)	0.95	0.89	0.90	0.92
Overbite (mm)	0.98	0.97	0.95	0.97
Soft tissue profile				
Upper lip to E-plane	0.99	0.99	0.97	0.99
Lower lip to E-plane	0.99	0.99	0.98	0.99
Soft tissue N vertical (true vertica) to upper lip (mm)	0.89	0.92	0.82	0.81
Soft tissue N vertical (true vertical) to lower lip (mm)	0.92	0.94	0.75	0.86
Soft tissue N vertical (true vertical) to ST pogonion (mm)	0.94	0.97	0.78	0.89
Soft tissue N perpendicular to upper lip (mm)	0.91	0.91	0.69	0.90
Soft tissue N perpendicular to lower lip (mm)	0.94	0.95	0.87	0.94
Soft tissue N perpendicular to ST pogonion (mm)	0.96	0.97	0.91	0.96

Table 2

Summary of ICCs for Each Head Orientation and Between-Head Orientations

	Within-Head Orientations					
	3D IRPes		**Simulated NHP**		**Between-Head Orientations**	
Range	n	%	n	%	n	%
ICC ≥ 0.90	45	90	36	72	21	42
0.75 < ICC < 0.90	5	10	11	22	21	42
0.45 < ICC ≤ 0.75	0	0	3	6	8	16
Total	50	100	50	100	50	100

Table 3

Range of Maximum Mean Differences Between IRP and NHP for the 50 Measurements, Controlling for Observer and Patient

	Maximum Mean Difference Between Head Orientations	
Range	**n**	**%**
Angular measurements		
$\bar{x} \geq 2°$	4	8
$1° < \bar{x} < 2°$	11	22
$0.5° < \bar{x} \leq 1°$	1	2
Linear measurements		
$\bar{x} \geq 2$ mm	10	20
$1 < \bar{x} < 2$	10	20
$0.5 < \bar{x} \leq 1$	10	20
$\bar{x} \leq 0.5$	4	8
Total	50	100

Table 4

Measurements That Showed Statistically Significant Difference Between Head Orientations ($P < .05$)

Measurements	**Maximum Mean Difference Between Head Orientations**	***P* Value**
Skeletal		
SNB (°)	1.2	.019
FMA (°)	1.3	.044
SN-GoGn (°)	1.9	.028
A point to nasion vertical (mm)	2.3	<.001
B point to nasion vertical (mm)	3.8	<001
Pogonion to nasion vertical (mm)	4.3	<.001
Soft tissue profile		
Soft tissue nasion vertical to upper lip (mm)	2.7	<.001
Soft tissue nasion vertical to lower lip (mm)	3.1	<.001
Soft tissue nasion vertical to ST pogonion (mm)	4.3	<.001