

Three-dimensional reproducibility of natural head position

Diana W. Weber,^a Drew W. Fallis,^b and Mark D. Packer^c

San Antonio, Tex

Introduction: Although natural head position has proven to be reliable in the sagittal plane, with an increasing interest in 3-dimensional craniofacial analysis, a determination of its reproducibility in the coronal and axial planes is essential. This study was designed to evaluate the reproducibility of natural head position over time in the sagittal, coronal, and axial planes of space with 3-dimensional imaging. **Methods:** Three-dimensional photographs were taken of 28 adult volunteers (ages, 18-40 years) in natural head position at 5 times: baseline, 4 hours, 8 hours, 24 hours, and 1 week. Using the true vertical and horizontal laser lines projected in an iCAT cone-beam computed tomography machine (Imaging Sciences International, Hatfield, Pa) for orientation, we recorded references for natural head position on the patient's face with semipermanent markers. By using a 3-dimensional camera system, photographs were taken at each time point to capture the orientation of the reference points. By superimposing each of the 5 photographs on stable anatomic surfaces, changes in the position of the markers were recorded and assessed for parallelism by using 3dMDvultus (3dMD, Atlanta, Ga) and software (Dolphin Imaging & Management Solutions, Chatsworth, Calif). **Results:** No statistically significant differences were observed between the 5 time points in any of the 3 planes of space. However, a statistically significant difference was observed between the mean angular deviations of 3 reference planes, with a hierarchy of natural head position reproducibility established as coronal > axial > sagittal. **Conclusions:** Within the parameters of this study, natural head position was found to be reproducible in the sagittal, coronal, and axial planes of space. The coronal plane had the least variation over time, followed by the axial and sagittal planes. (Am J Orthod Dentofacial Orthop 2013;143:738-44)

Natural head position (NHP) was first described by Broca¹ in 1862 as a stable physiologic position “when a man is standing and his visual axis is horizontal.” In 1958, Moorrees and Kean² defined it more specifically as “a standardized and reproducible orientation of the head in space when one is focusing

on a distant point at eye level.” As potential applications of NHP in cephalometric analysis were demonstrated, the claims of standardization and reproducibility came under greater scrutiny; however, numerous studies supported the stability of each patient's NHP in the sagittal plane. Bjerin³ and Moorrees and Kean² found deviations ranging from 1.3° to 2°; Lundström et al⁴ found variations of 1.5° to 2° using cephalometric radiography combined with photography, and Cooke and Wei⁵ found a 1.9° deviation using a mirror for orientation. In the latter study, cephalograms repeated 15 years later demonstrated a 2.2° deviation from the baseline measurements.⁶ Although most research supports the reproducibility of NHP, deviations were reported by Vig et al⁷ in patients with total nasal obstruction and by Achilleos et al⁸ as a physiologic adaptation to orthognathic surgery. However, in the latter study, NHP was restored to its original position 1 year postsurgery.

Methods to record NHP have varied in the literature; however, a cephalometric radiograph with a plumb line chain was first used and proved to be easily incorporated into clinical practice.⁹ Other methods have involved

^aResident, Tri-Service Orthodontic Residency Program, Air Force Postgraduate Dental School and Uniformed Services University of the Health Sciences, Lackland Air Force Base, San Antonio, Tex.

^bDepartment chairman, Tri-Service Orthodontic Residency Program, Air Force Postgraduate Dental School and Uniformed Services University of the Health Sciences, Lackland Air Force Base, San Antonio, Tex.

^cExecutive director, Department of Defense Hearing Center of Excellence; chief, Neurology and Cranial Base Surgery, San Antonio Military Health System, San Antonio, Tex.

The authors report no commercial, proprietary, or financial interest in the products or companies described in this article.

The views expressed in this article are those of the authors and do not reflect the official policy of the Department of Defense or other departments of the United States government.

Reprint requests to: Drew W. Fallis, Tri-Service Orthodontic Residency Program, 59th DTS/SGTR, 2133 Pepperell St, Lackland AFB, San Antonio, TX 78236-5551; e-mail, drew.fallis@us.af.mil.

Submitted, July 2012; revised and accepted, November 2012.

0889-5406/\$36.00

Copyright © 2013 by the American Association of Orthodontists.

<http://dx.doi.org/10.1016/j.ajodo.2012.11.026>

more complicated instrumentations, such as registration jigs,¹⁰ eyeglasses with inclinometers attached to the frames,¹¹ and 3-dimensional laser scanners to record NHP.¹²

Stimulated by the recent increased interest in 3-dimensional cone-beam computed tomographic imaging for orthodontic evaluation, studies demonstrating and testing various methods to record NHP 3 dimensionally have appeared in the literature. Xia et al¹³ used stereolithographic skull models of patients to demonstrate the 3-dimensional reproducibility of NHP. Recently, Koerich de Paula et al¹⁴ tested the effectiveness of minisensors in capturing changes with 6 degrees of freedom using NHP and stereophotogrammetry. Although their study demonstrated that the reproducibility of NHP is enhanced with the use of sensors, they concluded that spatial head position acquisition still requires additional registration procedures.

Although the use of 3-dimensional cone-beam computed tomography (CBCT) offers certain diagnostic advantages over conventional 2-dimensional cephalometric analysis, there are difficulties in orienting the volume in existing 3-dimensional imaging software programs because of the absence of external references during the CBCT acquisition process. Additionally, to reduce the amount of motion artifacts during the image acquisition process, it is helpful to use a head strap to restrain the patient's head to the headrest, especially in younger patients. Any head restraint device, however, would obviously affect the patient's physiologic head position. As an alternative, Cevidane et al¹⁵ presented a method of positioning the CBCT volume in the software with a simulated NHP, but it was not a true physiologically based head position.

Because of limitations in conventional 2-dimensional methodology and the need for additional radiographic images, few studies have evaluated NHP in 3 planes of space. However, with stereophotogrammetry, it is now possible to evaluate the reproducibility of the coronal, sagittal, and axial planes of space without cephalometric radiography. This study was designed to expand on the known reproducibility of NHP in the sagittal plane and to evaluate reproducibility in the coronal and axial planes over time by using a simplified technique that could be applied to the CBCT acquisition process.

MATERIAL AND METHODS

Twenty-eight adult active-duty military personnel, aged 18-40 years, were selected to participate in this longitudinal study conducted at the 3-dimensional imaging department at the Tri-Service Orthodontic Residency Program, Joint Base San Antonio, Lackland



Fig 1. I-CAT imaging system used to register NHP.

Air Force Base in San Antonio, Tex. The protocol was approved by the biomedical institutional review board, and informed consent was obtained from all subjects.

A studio was created to facilitate standardized light conditions and support all necessary equipment. As illustrated in Figure 1, the subjects were asked to sit in an iCAT CBCT machine (Imaging Sciences International, Hatfield, Pa), but no radiographic scans were taken of the subjects. The iCAT device was only used as a reference to place orientation ink points on the faces by using the machine's laser light beams projected to register true horizontal and vertical lines. Adjustments to seating heights were made to assist the subjects in achieving proper placement of the laser lines on their faces.

The subjects were asked to tilt their heads forward and backward with decreasing amplitude until they came to a comfortable position, and a natural head balance was reached. Once they were comfortable, they were asked to look directly into their own eyes in a mirror, which was mounted on a door directly in front of them at a distance of 7 feet, and finalize their head position.

By using semipermanent Sharpie markers (Newell Rubbermaid Office Products, Oak Brook, Ill), 4 ink dots were placed along the laser light beams: 2 dots were placed in the vertical plane along the forehead and on the midface including the tip of the nose, and 2 dots were placed in the horizontal plane on the preauricular and infrazygomatic areas. The subjects were then escorted to the photographic area for facial imaging with the stereophotographic imaging system (3dMD, Atlanta, Ga) as illustrated in Figure 2. At each time point, the process was repeated, placing dots to register NHP, followed



Fig 2. 3dMD stereophotographic system used to record the registration dots.

by a 3-dimensional photograph. Photographs were taken at 5 times: initial baseline, and 4 hours, 8 hours, 24 hours, and 1 week later.

Three-dimensional surface images were obtained by using the Face multicamera system (3dMD), which was calibrated before each imaging session. The stereophotography unit uses 4 cameras: 2 positioned on either side of the subject. It covers a 180° face capture (ear to ear), has a capture speed of 1.5 ms at the highest resolution, and is reported by the manufacturer to have a clinical accuracy of 1.5% of total observed variance.

All photographic images were exported as .tbs files and imported into the 3dMDvultus imaging software (3dMD) in which digital models were reconstructed from the data, and the ink dots were digitized. As illustrated in Figure 3, the initial image was oriented to align the digitized ink dots with the axial and sagittal planes in the software and then digitally locked to the image with the software tools. The coronal plane was established as the resultant perpendicular to both the axial and sagittal planes. Two points were then digitized on the computer-generated coronal plane and locked in place with the software tool. A line segment was constructed connecting the 2 digitized points in each plane for comparison with future time points.

Subsequent facial images (4 hours to 1 week later) of each subject were superimposed over the baseline image to determine changes in the 3 dimensions of space for each time interval. As illustrated in Figure 4, with the 3dMDvultus imaging software, a systematic process was used by manually aligning the facial photographs on a subject's forehead (brow area) and under the eyes, as described by Incrapera et al.¹⁶ The images were superimposed by using the broadest area of the anterior position of the forehead, including soft-tissue

glabella, soft-tissue nasion, and the bridge of the nose to incorporate a regional fit environment.

Screen captures were completed for all superimpositions in the sagittal, axial, and coronal planes to capture the relationship of the 2 lines observed on the 2 superimposed images. These screen captures were exported into software (Dolphin Imaging & Management Solutions, Chatsworth, Calif) as .jpeg files. Angular differences were measured between the 2 lines as depicted in Figure 5. The Dolphin Imaging software was used because of its ability to measure closely parallel lines with 4 digitized points (2 points digitized on each line segment from the separate time point images that were superimposed).

Statistical analysis

An a priori power analysis showed that a sample size of 28 participants with 15 observations per participant (5 time points and 3 planes) would provide a statistical power of 99% with a small effect size of 0.25 (standard deviation of 52, approximately) and an alpha (probability of type I error) equal to 0.05 ($P = 0.05$).

A mean and standard deviation were initially calculated for 1 subject measured 10 times in each plane to assess the variations of the measurement method. For the main study, means and standard deviations were calculated for each time point and then compared statistically with repeated-measure analysis of variance (ANOVA). Comparisons were completed between the mean measurements of all 5 time points for each reference plane by an unpaired Student *t* test with the Bonferroni correction.

RESULTS

One subject was evaluated, and measurements at the 5 time points were compared for each of the 3 planes, 10 times. The variability of the measurement method demonstrated a standard deviation of 0.10°.

Means and standard deviations were calculated and comparisons made between each of the 3 planes (Table 1, Fig 6). Comparison of the means with repeated-measures ANOVA showed no statistically significant differences between the measured deviations over time ($P > 0.05$) (Table I). Additionally, pair-wise comparisons with the Bonferroni correction were completed to compare the mean deviations of the 3 planes. The mean coronal plane deviation was significantly less than the axial plane, which was significantly less than the sagittal plane (Table II).

DISCUSSION

The results of this study demonstrate that NHP is reproducible in 3 planes of space over time, a finding



Fig 3. Registration of the axial and sagittal planes in the 3dMDvultus software corresponding to the ink dots (*white arrows*). The coronal plane (not pictured) was the computer-generated perpendicular to both the axial and sagittal planes.

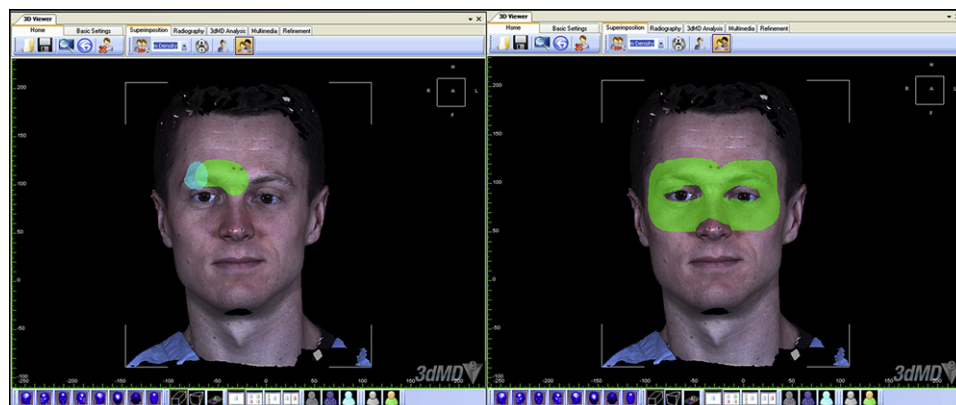


Fig 4. Areas of superimposition with the 3dMDvultus software.

that is consistent with previously published literature pertaining to the sagittal plane. NHP registrations have been measured in the sagittal plane with 1.5° to 2.5° of deviation when compared at various times.^{2,5} Cooke and Wei⁵ measured a 1.9° deviation using a mirror after 4 to 10 minutes and compared this value with measurements taken 1 to 2 hours later. When the procedure was

repeated at 3 to 6 months, a 2.4° method of error was found. Peng and Cooke,⁶ in a longitudinal study, radiographed 20 of the original subjects and found a 2.2° difference after 15 years, compared with 3° at 5 years. The results of this study are consistent with Cooke and Wei's findings for the short term; however, time points past 1 week were not included in our study to

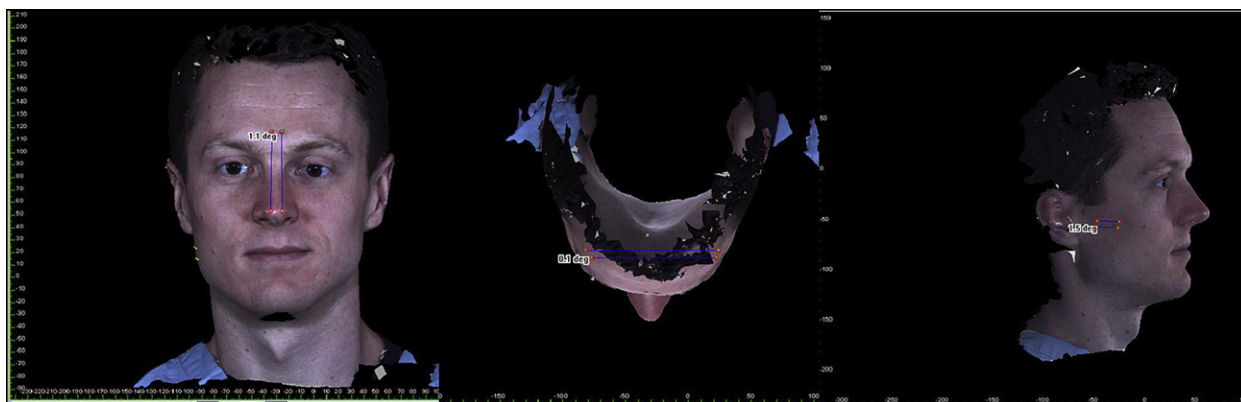


Fig 5. Measurement of angular differences between *lines* by using the Dolphin Imaging software.

Table I. Means and standard deviations for each time interval

Reference plane comparison	T1-T2	T1-T3	T1-T4	T1-T5	P value
Sagittal	1.48 (1.23)	1.66 (1.67)	1.7 (1.04)	1.85 (1.38)	0.78
Axial	1.04 (0.84)	1.01 (0.94)	1.28 (0.95)	1.33 (1.0)	0.49
Coronal	0.5 (0.70)	0.49 (0.61)	0.55 (0.71)	0.73 (0.71)	0.55

Comparisons via repeated-measure ANOVA, with the threshold established at $P \leq 0.05$ for statistical significance.

T1, Baseline; T2, 4 hours later; T3, 8 hours later; T4, 24 hours later; T5, 1 week later.

compare with their long-term results. This study demonstrated that the coronal plane had less variation than did the axial, and both had less variation than the sagittal. This finding can best be explained by known biologic factors affecting head position in the 3 planes of space.

Since the head is centered vertically on its axis, positional deviations are minimized. Using the analogy of a 2-liter bottle balanced on its top, if you rotate the bottle, positional deviation will occur, but the bottle remains balanced on its central vertical axis. Likewise, when measuring coronal plane deviations associated with a patient's NHP, the head is balanced by large muscle groups offering only slight flexion or extension across a central vertical axis. Additionally, as a subject is asked to look directly into his or her own eyes, a visual cue is present that is framed by the obvious protrusions of the brow and nose that guides repositioning and prevents subtle flexion or extension of the head. Physiologically, head position in the coronal plane is controlled by the vestibuloocular and vestibulospinal reflexes, as well as inner ear otolithic gravitational responses that provide interactions between eye

position, head position, and muscles, all of which influence the movement and positioning of the head in relation to the spine. Therefore, the coronal axis provides more clues when the subject attempts to maintain or duplicate head position and hence is the most reproducible over time.

As the head moves from side to side (as in axial plane deviations) or in varying oscillations up and down (as in sagittal plane deviations), 20 muscles in the neck are triggered to respond.¹⁷ As a result, maintaining a consistent head position becomes more complicated when the trunk and the lower extremities become involved in maintaining the body in balance. Physiologically, patients rely on 2 reflexes to help stabilize the head in the sagittal and axial planes. The first is the vestibulocollic reflex, when the muscles of the neck respond to vestibular input. The second, the cervicocollic reflex, governs the response of the neck to stretch receptors. Maintaining positional stability in the sagittal plane requires a combination of positional memory, muscle tone, muscle memory, and visual response as a person sits or stands in the same position. The weight of the head might also be a significant factor in the finding that patients demonstrate greater deviation in the sagittal plane when assuming NHP, since gravity adversely influences the balance of the head and the alignment with the spine. Additionally, patients can be more tolerant of deviations in the sagittal plane based on daily movements. For instance, subjects typically position their heads downward while working on a computer or reading a newspaper; this can lead to habitual, tolerated, and unbalanced positioning of the head in the sagittal plane.

Positioning the head in the axial plane largely depends on inner ear balance from stimulation of the vestibular system and then supported by muscle balance and visual input. According to Brodal and

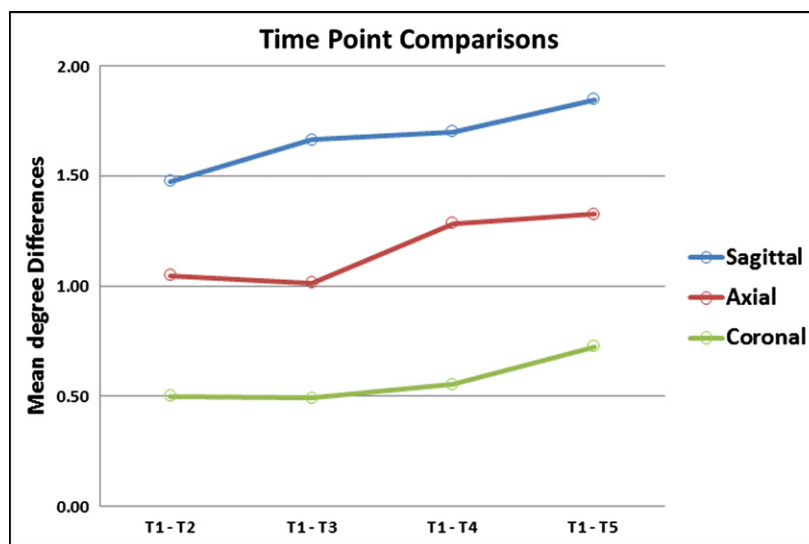


Fig 6. Time point comparisons in the 3 planes.

Table II. Statistical comparison of all planes

Reference plane comparison	P value
Sagittal-axial	0.013*
Axial-coronal	0.002*
Coronal-sagittal	0.000*

*Statistically significant difference at the $P \leq 0.05$ level.

Pompeniano,¹⁸ the vestibular system plays a significant role in terms of its response to motion and spatial orientation of the head. The ear contains 2 structures, the utricle and saccule, as well as 3 semicircular canals, all filled with fluid. The cilia in the ear become stimulated or polarized by the fluid as the head moves in any direction. This 3-coordinate system, made up of the semicircular canals oriented in the sagittal, axial, and coronal planes, allows any direction of rotation to be recognized when the discharges from the 3 canals are combined. Concurrently, these motions provide reflexive coordination of eye movements to maintain visual focus on a subject. The tilt of the head from side to side stimulates movement of hair bundles, and the person receives input to refocus the eyes in opposition to the movement. Avoidance of a tilt of the head from left or right also demonstrates a protective instinct to maintain the head centered over the axis of the spine to prevent fatigue or injury. This function is coordinated by the otolithic organs, which are gravitationally based and respond to linear rather than angular acceleration. As an example of this protective mechanism, the cradling of a phone between the head and the shoulder can

cause a “kink” in the neck, resulting in the neck muscles signaling that the interference should be corrected.

Therefore, the human body demonstrates physiologic processes and reflexes that allow reproducible 3-dimensional positioning of the head in space. For orthodontic purposes, it can be theorized that using constructed planes of reference based on each patient’s physiologic head position could enhance the assessment of craniofacial changes in a growing patient. Rather than relying solely on internal reference planes based on skeletal landmarks that can undergo significant remodeling during growth and orthodontic treatment, use of extracranial references based on NHP might prove to be useful for patient analysis. The integration of NHP registration with CBCT and stereophotographic digital reconstructions of the patient would allow analysis with intracranial or extracranial planes of reference, whichever is deemed to be optimal for that patient at the time. Since we assessed the reproducibility of NHP over only a 1-week period in this study, a time frame with minimal soft-tissue change expected, future research would be required to determine the reproducibility over a longer period of time using this method of superimposition.

CONCLUSIONS

Within the parameters of this study, it can be concluded that NHP is reproducible in the coronal, axial, and sagittal planes of space over time. The degree of variation differs between the 3 planes, with a hierarchy of reproducibility established as

coronal > axial > sagittal; this finding can be explained by documented physiologic factors.

We thank Jesse Knowles for his expertise and guidance with the 3dMD imaging system and Maharaj Singh for statistical support.

REFERENCES

1. Broca M. Sur les projections de la tête, et sur un nouveau procédé de céphalométrie. *Bull Soc Anthropol Paris* 1862;3:514-44.
2. Moorrees CFA, Kean MR. Natural head position, a basic consideration in the interpretation of cephalometric radiographs. *Am J Phys Anthropol* 1958;16:213-34.
3. Bjerin R. A comparison between the Frankfort horizontal and the sella turcica-nasion as reference planes in cephalometric analysis. *Acta Odontol Scand* 1957;15:1-13.
4. Lundström A, Lundström F, Le Bret LM, Moorrees CF. Natural head position and natural head orientation: basic considerations in cephalometric analysis and research. *Eur J Orthod* 1995;17:111-20.
5. Cooke MS, Wei SH. The reproducibility of natural head position: a methodological study. *Am J Orthod Dentofacial Orthop* 1988;93:280-8.
6. Peng L, Cooke MS. Fifteen-year reproducibility of natural head posture: a longitudinal study. *Am J Orthod Dentofacial Orthop* 1999;116:82-5.
7. Vig PS, Showfety KJ, Philips C. Experimental manipulation of head posture. *Am J Orthod* 1980;77:258-68.
8. Achilleos S, Krogstad O, Lyberg T. Surgical mandibular setback and changes in uvuloglossopharyngeal morphology and head posture: a short and long term cephalometric study in males. *Eur J Orthod* 2000;22:383-94.
9. Proffit WR, Fields HW. *Contemporary orthodontics*. 3rd ed. St Louis: Mosby; 2000.
10. Schatz EC, Xia JJ, Gateno J, English JD, Teichgraber JF, Garrett FA. Development of a technique for recording and transferring natural head position in 3 dimensions. *J Craniofac Surg* 2010;21:1452-5.
11. Usume S, Orhan M. Inclinator method for recording and transferring natural head position in cephalometrics. *Am J Orthod Dentofacial Orthop* 2001;120:664-70.
12. Soncul M, Bamber MA. The reproducibility of the head position for a laser scan using a novel morphometric analysis for orthognathic surgery. *Int J Oral Maxillofac Surg* 2000;29:86-90.
13. Xia JJ, Gateno J, Teichgraber JF. New clinical protocol to evaluate craniomaxillofacial deformity and plan surgical correction. *J Oral Maxillofac Surg* 2009;67:2093-106.
14. Koerich de Paula L, Ackerman JL, Riberiro Carvalho FA, Eidson L, Cevidanes LHS. Digital live-tracking 3-dimensional minisensors for recording head orientation during image acquisition. *Am J Orthod Dentofacial Orthop* 2012;141:116-23.
15. Cevidanes L, Oliveira A, Motta A, Phillips C, Burke B, Tyndall D. Head orientation in CBCT-generated cephalograms. *Angle Orthod* 2009;79:971-7.
16. Incrapera AK, Kau CH, English JD, McGrory K, Sarver DM. Soft tissue images from cephalograms compared with those from a 3D surface acquisition system. *Angle Orthod* 2010;80:58-75.
17. Flint PW, Haughey BH. *Cummings otolaryngology head and neck surgery*. 5th ed. Philadelphia: Mosby; 2010. p. 2305-27.
18. Brodal A, Pompeniano O. *Basic aspects of central vestibular mechanisms*. Amsterdam, The Netherlands: Elsevier; 1972.