AJO-DO

Modified method of recording and reproducing natural head position with a multicamera system and a laser level

Xiao-jing Liu,[a] Qian-qian Li,[b] Yuan-jie Pang,[c] Kai-yue Tian,[d] Zheng Xie,[e] and Zi-li Li[f]
Beijing, China, and Baltimore, Md

Introduction: As computer-assisted surgical design becomes increasingly popular in maxillofacial surgery, recording patients' natural head position (NHP) and reproducing it in the virtual environment are vital for preoperative design and postoperative evaluation. Our objective was to test the repeatability and accuracy of recording NHP using a multicamera system and a laser level. **Methods:** A laser level was used to project a horizontal reference line on a physical model, and a 3-dimensional image was obtained using a multicamera system. In surgical simulation software, the recorded NHP was reproduced in the virtual head position by registering the coordinate axes with the horizontal reference on both the frontal and lateral views. The repeatability and accuracy of the method were assessed using a gyroscopic procedure as the gold standard. **Results:** The interclass correlation coefficients for pitch and roll were 0.982 (0.966, 0.991) and 0.995 (0.992, 0.998), respectively, indicating a high degree of repeatability. Regarding accuracy, the lack of agreement in orientation between the new method and the gold standard was within the ranges for pitch (−0.69°, 1.71°) and for roll (−0.92°, 1.20°); these have no clinical significance. **Conclusions:** This method of recording and reproducing NHP with a multicamera system and a laser level is repeatable, accurate, and clinically feasible. (Am J Orthod Dentofacial Orthop 2015;147:781-7)

Natural head position (NHP) is the most reproducible relaxed head position adopted by a subject looking horizontally into infinity.[1] Two methods are described to determine NHP in the clinic. The first method asks the patient to look into horizontal infinity,[2] and second method asks the patient to look into his or her own eyes in a mirror.[3,4] Physiologically, head position is controlled by vestibulo-ocular and vestibulospinal reflexes, as well as by inner ear otolithic gravitational responses that provide interactions among eye position, head position, and muscles.[4] According to previous studies, NHP can be influenced by nasorespiratory function,[5-7] occlusion,[8-10] craniofacial skeletal morphologic features, and visual feedback deprivation.[11] Based on these findings, NHP might change with different emotional states, ages, personal characteristics, environmental conditions, and cervical discomfort.

Since NHP provides a coordinate reference system for taking measurements and therefore has vital importance for diagnosis, surgical design, postoperative outcome evaluation, and developmental tracking in patients with dentomaxillofacial deformities, it has gained the interest of many experts.[2,12,13] Previous studies have mainly focused on how to record NHP 2 dimensionally.[14-18] Now, with the development of computer-assisted surgical design, many authors are using new methods for recording 3-dimensional (3D) NHP and integrating it into a computer-assisted surgical design protocol.

[a]Doctor, Department of Oral and Maxillofacial Surgery, Peking University School and Hospital of Stomatology, Beijing, China.
[b]PhD student, Department of Oral and Maxillofacial Surgery, Peking University School and Hospital of Stomatology, Beijing, China.
[c]PhD student, Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, Md.
[d]PhD student, Department of Oral and Maxillofacial Surgery, Peking University School and Hospital of Stomatology, Beijing, China.
[e]PhD student, School of Public Health, Peking University Health Science Center, Beijing, China.
[f]Professor, Department of Oral and Maxillofacial Surgery, Peking University School and Hospital of Stomatology, Beijing, China.
All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
Financial support from the National High-Tech R&D Program (2012AA041606), the Capital Health Research and Development of Special (2011-4025-03), and the Foundation of Peking University School and Hospital of Stomotology (PKUSSNCT-13A02).
Address correspondence to: Zi-li Li, 22 Zhongguancun Avenue South, Haidian District, Beijing 100081, PR China; e-mail, kqlzl@sina.com.
Submitted, August 2014; revised and accepted, January 2015.
0889-5406/$36.00

http://dx.doi.org/10.1016/j.ajodo.2015.01.016

Schatz[2] and Xia[19] et al conducted a series of studies on how to record and reproduce NHP 3 dimensionally using a gyroscope. According to our experience, this method is accurate and feasible for preoperative design but impractical for postoperative evaluation and long-term follow-up.[20] The main reason for this limitation is that in the gyroscopic procedure, recording and reproduction are based on the alignment between the patient's occlusion and the gyroscope, and when the occlusion is altered after surgery, the alignment is also changed. As a consequence, the entire procedure, including the computed tomography (CT) scan, must be repeated at each follow-up visit, with an unacceptable increase in radiation exposure.[2,19] Other disadvantages of the gyroscopic procedure include (1) the requirement for specialized software and equipment such as a bite-jid, facebow, and acrylic materials; and (2) the total weight of the gyroscope that might affect head orientation because the weight is in front of the center of gravity.[2]

Weber[4] first reported the method of recording NHP using a stereophotographic system. In that study, the true vertical and horizontal laser lines were projected for orientation and then were marked on the patient's face with ink dots. Using a 3D camera system, photographs were taken to capture the orientation of the reference points. Compared with the gyroscope and the procedure of Schatz[2] and Xia[19] et al, Weber's method has the following advantages: (1) no special devices and software, (2) no occlusion alignment, and (3) no radiation exposure.

However, there is some uncertainty about the accuracy and convenience of the method of Weber[4] for 2 reasons. First, since head posture can be affected by visual motion, when doctors draw marking dots according to laser lines, patients may be distracted and move their head slightly. Second, the separate procedure of reference marking and taking 3D photographs will inconvenience both patients and doctors.

We modified the method of Weber[4] by capturing laser reference lines and the patient's face together, eliminating the marking of reference dots. This study was designed to test the accuracy and repeatability of this new technique. Since several variables can affect NHP, such as personal characteristics, environmental conditions, room heat, and a person's excitation state, this study was based on a physical model to eliminate other factors outside the technique itself.

MATERIAL AND METHODS

A physical head model (Brainlab, Munich, Germany) made from CT-compatible plastic material was used in the study. A digital gyroscope (3DM; MicroStrain, Williston, Vt) assembled with a facebow and reference markers (Medical Modeling, Golden, Colo) was fixed to the physical model by 2 titanium screws at each side to ensure a solid alignment between the gyroscope and the model throughout the study. A CT scan was acquired with a cone-beam CT scanner (VG; NewTom, Verona, Italy). The scanning matrix was 400 $\times$ 400 with a depth of gray level of 16 bits. The layer thickness was 0.075 mm with a field of view of 15 cm. The position of the model was recorded by the gyroscope simultaneously with the CT scanning. Data in DICOM format were transferred into Proplan CMF virtual design software (Materialise, Oberdorf, Switzerland). A virtual image of the model and the gyroscope assembly was obtained by surface rendering reconstruction of the DICOM data. The original coordinate system of the CT scan was quoted by the software, which was recorded by the gyroscope.

NHP was recorded by capturing a 3D image of the physical model with horizontal lines projected onto it by the laser level. The procedure was as follows.

First, a laser level (SaiWei, Shanghai, People's Republic of China) was used to project a horizontal line onto the physical model. As stated in the manufacturer's handbook, the wavelength of the laser beam was 635 to 670 nm, and the horizontal accuracy was 0.2 mm when the distance was 1 m. The distance between the physical model and the laser level in our test was 1.5 m. The laser level was set up in front of the model to enable the horizontal line to be projected across the entire face (Fig 1).

Second, a 3D image was obtained using a multicamera system (3dMD, Atlanta, Ga). This stereophotography unit uses 4 cameras, 2 of which are positioned on each side of the subject. It achieves a 180° face capture (ear to ear), with a capture speed of 1.5 ms and a resolution of 400 dpi. The reported accuracy in the manufacturer's handbook is 1.5% of the total observed variance. The center flashlight of the multicamera system was turned off so that the laser beam reference line appeared more clearly on the obtained images. The instruments and imaging environment are shown in Figure 2.

Because the 3D image captured the model from ear to ear, the horizontal reference line could be used to record both the pitch and roll orientations simultaneously. The frontal view was used to record the roll and the lateral view to record the pitch (Fig 3).

NHP was reproduced in the virtual model by altering the virtual head position until the both vertical and sagittal vectors coincided with the horizontal reference line. The procedure was as follows.

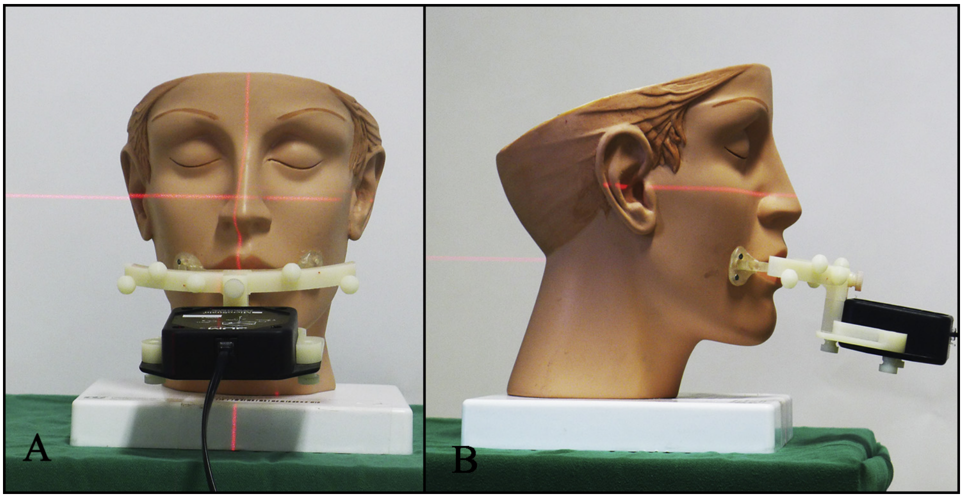

Fig 1. Projection of the horizontal laser beam on the physical model. A laser level was used to project a horizontal reference line from ear to ear on a physical model. The orientation was recorded simultaneously by a gyroscope. **A,** frontal view; **B,** lateral view.

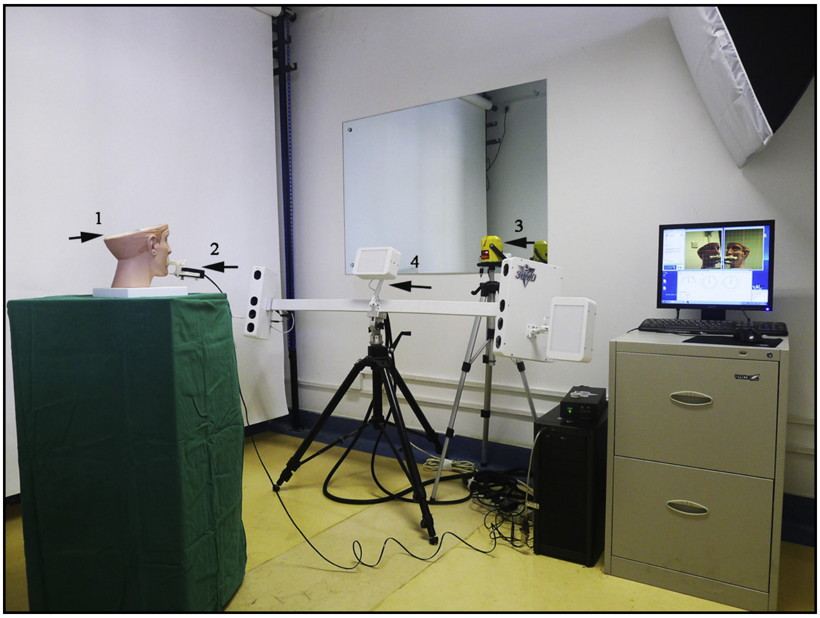

Fig 2. Instrument and imaging environment for natural head position recording: *1*, physical model; *2*, gyroscope; *3*, laser collimeter; *4*, 3D multicamera system.

1. The 3D camera image was saved in .wrl format and imported into the surgical design software.
2. The 3D image and the CT scan were superimposed through a surface registration procedure, with the CT scan set as the fixed object and the 3D image as the floating object.
3. The virtual head position was moved manually according to the horizontal laser beam line on the 3D image. In the virtual environment, the x-axis represents the horizontal vector, the y-axis represents the vertical vector, and the z-axis represents the sagittal vector. In this sense, pitch, yaw, and roll refer to the angles around these 3 axes, respectively. Thus, the x-axis coordinate was parallel to the line on the frontal view; simultaneously, the z-axis coordinate was parallel to the line on the lateral view (Fig 3).
4. The coordinate axis was double-checked from both views. The changes in the pitch and roll angles during the movement were recorded.

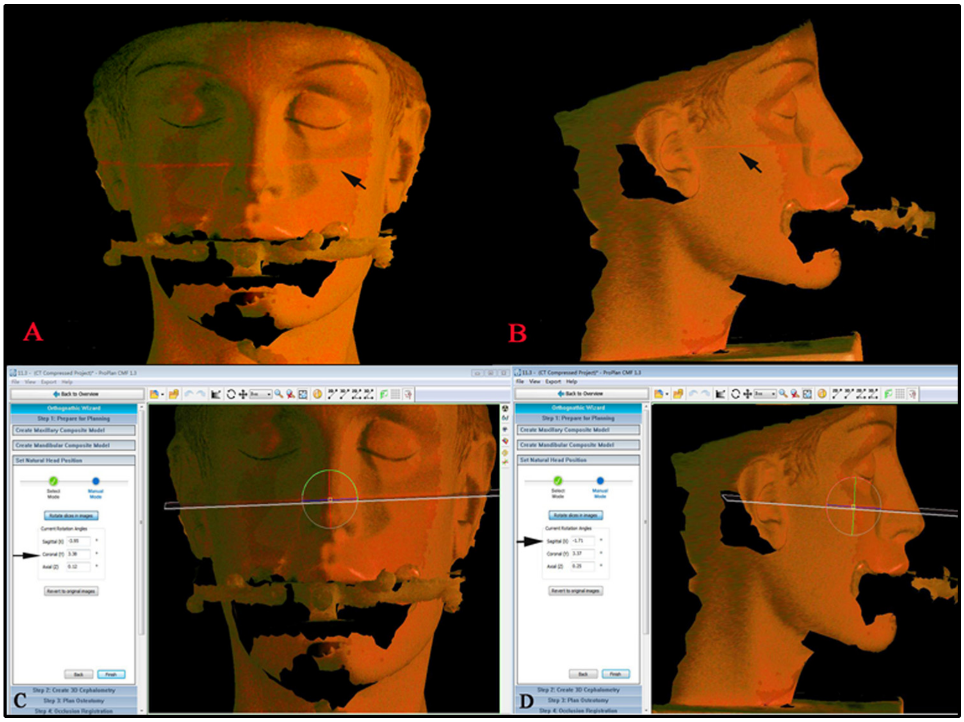

Fig 3. Reproduction of NHP in the virtual environment. **A** and **B,** 3D images of the physical model and horizontal reference line. The laser beam can be seen clearly (*arrows*). **C** and **D,** In the NHP modification dialog window, the virtual head position was moved manually according to the laser beam reference. In **C,** first, the head position was moved in the frontal view until the laser beam was parallel to the x-axis coordinate, altering the coronal angle or roll angle (*arrow*). In **D,** second, the head position was moved in the lateral view until the laser beam was parallel to the y-axis coordinate, altering the sagittal or pitch angle (*arrow*). Changes in pitch and roll angles were calculated in real time during registration and shown in the dialog box.

We used a gold standard for NHP recording and reproduction. The orientation of each head position was recorded by the digital gyroscope, by recording the pitch and roll angles simultaneously. The pitch and roll alterations between 1 test head position and the head posture during the CT scan were calculated. These alterations were the angles that needed to be applied when reproducing a recorded head position on the virtual model and were considered the gold standard.

This study was designed to answer 2 questions: (1) whether the results obtained with the new method depend on operator experience, and (2) whether the new method is as accurate as the gyroscopic method. Two tests were therefore used: the first to assess the repeatability of the new method among different operators, and the second to assess its accuracy.

For the repeatability tests, a minimum sample of 33 participants would yield an expected intraclass correlation coefficient (ICC) of 0.9 and a lowest acceptable ICC of 0.8 for 3 repetitions per participant. For the accuracy tests, the total sample size of 35 was determined before the study based on an expected difference of 2 between measurements and the gold standard. This sample size would yield an alpha of 0.05 and a power of 0.80.

During the recording procedure, the physical model was randomly oriented 35 times so that 35 pairs of data were obtained, comprising both the corresponding angles recorded by the multicamera system and the laser level, and the angles recorded by the gyroscope. During the reproduction procedure, 3 experienced orthognathic surgeons (X.-j.L., Z.-l.L., and another) independently registered the virtual head. The resultant pitch and roll angles were recorded. The experimental design is shown in Figure 4.

Statistical analysis

All statistical analyses were performed with Stata software (version 13; StataCorp, College Station, Tex). For the repeatability test, a 2-way mixed-effects model (absolute agreement definition) for the ICC was initially computed to determine whether the reproductions made

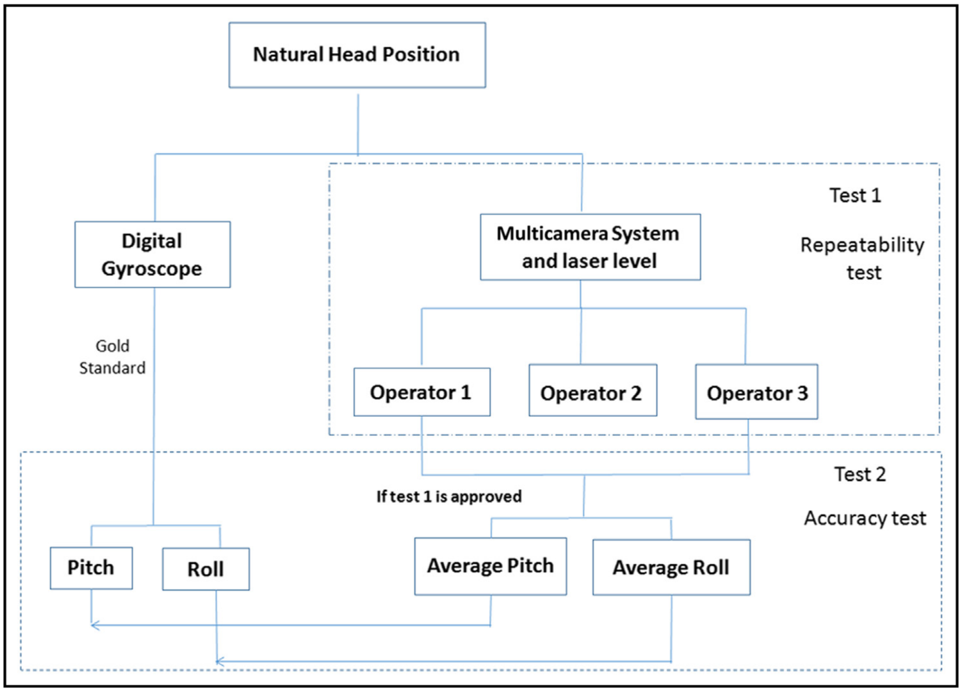

Fig 4. Study design.

Table. Accuracy of the new method

Delta mean (°)	*SD (°)*	*95% CI of bias (°)*	*Lower limit of agreement (95% CI) (°)*	*Upper limit of agreement (95% CI) (°)*
Pitch, 0.51	0.61	0.28, 0.73	−0.69 (−1.10, −0.32)	1.71 (1.34, 2.12)
Roll, 0.14	0.54	−0.062, 0.34	−0.92 (−1.28, −0.60)	1.20 (0.88, 1.56)

by the different operators agreed. If they statistically and absolutely agreed, the measurements were averaged in the accuracy test.

For the accuracy test, a 1-sample t test was performed to determine whether the delta values for the new method and the gold standard for each orientation (pitch or roll) were statistically different from 0°. If delta was significantly different from 0°, a 1-sample t test was performed to determine whether it was statistically different from 2° because, according to previous studies, there would be no clinically significant difference if the lack of agreement was less than 2°.[21]

Finally, the methods of Bland and Altman[22] were used to assess the agreement between measurements. The data were screened, and the assumption of normal distribution could not be rejected. The accuracy of our method is presented as means and standard deviations of delta values, 95% confidence intervals (CI) of the bias (the precision of the estimated mean difference of agreements), and lower and upper limits of the agreement and their 95% CI.

Results

In the repeatability test, the ICC values of the operators for pitch and roll were 0.982 (0.966, 0.991) and 0.995 (0.992, 0.998), respectively. This indicates a high degree of repeatability.

In the accuracy test, the delta values for the roll angles measured in the new NHP reproduction procedure and the gold standard were not statistically significantly different from 0° ($P = 0.169$). The delta value for the pitch angle was statistically significantly different from 0° ($P < 0.001$); however, it was significantly less than 2° ($P < 0.001$). This indicates that the pitch measurement was significantly overestimated, but the bias was within 2°.

The findings regarding the efficacy of the method as assessed by the methods of Bland and Altman[22] are shown in the Table. The lack of agreement in orientation between the test and the gold standard was within the ranges for pitch (−0.69°, 1.71°) and for roll (−0.92°, 1.20°), indicating no clinically significant difference.

DISCUSSION

Computer-assisted design is becoming increasingly popular in orthognathic surgery, trauma reconstruction, and craniofacial deformity correction. When basing a virtual design on CT data, it is important to reproduce the patient's NHP in the virtual model because the measurements should be based on a natural coordinate system.[23] Furthermore, the recorded NHP should be easily reproduced when obtaining postoperative follow-up images to enable use of the same reference planes when evaluating facial protrusion and asymmetry.

The ideal method for recording and reproducing NHP should be reproducible, accurate, and independent of the operator. Most importantly, it should not influence the position of the patient's head during recording.[3] In the past, when surgical designs were mainly based on cephalometry and model surgery, the methods of recording NHP involved taking standard photographs and obtaining cephalograms[17,21,24-29] with a horizontal reference system or recording angles with special instruments.[3] Although these methods cannot be applied to 3D virtual systems, which are increasingly popular in surgical design, their basic principles can still be followed. In this study, we followed the principle of imaging horizontal reference lines on the face using a 3D camera system.

Errors can occur during the reproduction procedure because the virtual head position is set manually according to the reference lines. In this study, we demonstrated that our new method is highly reliable, with ICC values among the 3 operators of more than 0.99 for both the pitch and roll angles. We also found that the new method met the clinical requirement for accuracy. The bias in roll was not significantly different from 0°. The bias in pitch was larger than 0°, but the absolute values of the upper and lower limits of agreement were less than 2°; this is considered clinically accurate.[21] The main reason for this finding might be that reference lines in the lateral area were shorter and could have been distorted because the laser beam was not projected directly onto the model's lateral surface. Higher accuracy could be achieved by using equipment with 3 laser beams assembled at the same horizontal level so that the beams are projected simultaneously and directly on the frontal and bilateral areas without distortion.

Compared with the method of Weber,[4] the advantages of this new technique are that (1) it prevents errors caused by the manual drawing of ink dots along the horizontal laser beam, and (2) a complete horizontal line instead of 2 dots appears across the image, facilitating NHP reproduction.

Compared with gyroscopic procedures, the accuracy of this new method is comparable for roll but reduced for pitch. However, the new method is quick, does not expose the patient to radiation, is easy to perform, and saves time and the expense of purchasing specialized software and gyroscope assemblies. These advantages make the new method more feasible for use in postoperative evaluation and follow-up. This method could also be used to record 3D reference lines in any orientation, in addition to horizontal and vertical.

Since this study was based on a physical model, the resulting accuracy represents standards only for the technique protocol, which mainly refers to surface registration and manual modification procedures. In clinical practice, the patient's head posture will be affected by many variables, such as medical instruction, light, physical state, or even emotion. How to regulate the viewing field of the stereophotographic system and the light system to make the laser lines as clear as possible is a major concern affecting the in-vivo use of this procedure. Further investigations are needed to identify the accuracy and repeatability of clinical procedures. Our results will be a useful reference for the analysis and understanding of in-vivo results.

CONCLUSIONS

The method of recording and reproducing NHP with a multicamera system and a laser level is repeatable, accurate, and clinically feasible.

REFERENCES

1. Moorrees CF. Natural head position—a revival. Am J Orthod Dentofacial Orthop 1994;105:512-3.
2. Schatz EC, Xia JJ, Gateno J, English JD, Teichgraeber JF, Garrett FA. Development of a technique for recording and transferring natural head position in 3 dimensions. J Craniofac Surg 2010;21:1452-5.
3. Usumez S, Orhan M. Inclinometer method for recording and transferring natural head position in cephalometrics. Am J Orthod Dentofacial Orthop 2001;120:664-70.
4. Weber DW, Fallis DW, Packer MD. Three-dimensional reproducibility of natural head position. Am J Orthod Dentofacial Orthop 2013;143:738-44.
5. Huggare JA, Laine-Alava MT. Nasorespiratory function and head posture. Am J Orthod Dentofacial Orthop 1997;112:507-11.
6. Lundstrom A. Natural head position/a discussion of concepts. Br J Orthod 1990;17:249-50.
7. Weber ZJ, Preston CB, Wright PG. Resistance to nasal airflow related to changes in head posture. Am J Orthod 1981;80:536-45.
8. AlKofide EA, AlNamankani E. The association between posture of the head and malocclusion in Saudi subjects. Cranio 2007;25:98-105.
9. Barbera AL, Sampson WJ, Townsend GC. Variation in natural head position and establishing corrected head position. Homo 2014;65:187-200.
10. Andrighetto AR, Fantini SM. Effects of neuromuscular deprogramming on the head position. Cranio July 22, 2014 [Epub ahead of print].
11. Vig PS, Showfety KJ, Phillips C. Experimental manipulation of head posture. Am J Orthod 1980;77:258-68.

12. Lin XP, Arild S. Longitudinal study of the stability and reproducibility of natural head position in adolescents with different facial types over time. Shanghai Kou Qiang Yi Xue 2005;14:238-42.
13. Dubojska AM, Smiech-Slomkowska G. Natural head position and growth of the facial part of the skull. Cranio 2013;31:109-17.
14. Showfety KJ, Vig PS, Matteson S. A simple method for taking natural-head-position cephalograms. Am J Orthod 1983;83:495-500.
15. Viazis AD. A cephalometric analysis based on natural head position. J Clin Orthod 1991;25:172-81.
16. Leitao P, Nanda RS. Relationship of natural head position to craniofacial morphology. Am J Orthod Dentofacial Orthop 2000;117:406-17.
17. Robertson C. Cranial base considerations between apnoeics and non-apnoeic snorers, and associated effects of long-term mandibular advancement on condylar and natural head position. Eur J Orthod 2002;24:353-61.
18. Usumez S, Orhan M. Reproducibility of natural head position measured with an inclinometer. Am J Orthod Dentofacial Orthop 2003;123:451-4.
19. Xia JJ, McGrory JK, Gateno J, Teichgraeber JF, Dawson BC, Kennedy KA, et al. A new method to orient 3-dimensional computed tomography models to the natural head position: a clinical feasibility study. J Oral Maxillofac Surg 2011;69:584-91.
20. Liu XJ, Li QG, Tian KY, Wang XX, Zhang Y, Li ZL. Establishment and accuracy examination of gyroscope for recording and transferring natural head position. Beijing Da Xue Xue Bao 2014;46:86-9.
21. Lundstrom F, Lundstrom A. Natural head position as a basis for cephalometric analysis. Am J Orthod Dentofacial Orthop 1992;101:244-7.
22. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307-10.
23. Hattori T. An alternative cephalometric evaluation based on the concept of natural head position. Nihon Kyosei Shika Gakkai Zasshi 1985;44:727-33.
24. Halazonetis DJ. Estimated natural head position and facial morphology. Am J Orthod Dentofacial Orthop 2002;121:364-8.
25. Ding XJ, Qian YF, Cao HJ, Tang GH. A cephalometric study of natural head posture and spinal position in malocclusions. Shanghai Kou Qiang Yi Xue 2002;11:303-6.
26. Raju NS, Prasad KG, Jayade VP. A modified approach for obtaining cephalograms in the natural head position. J Orthod 2001;28:25-8.
27. Lundstrom A, Lundstrom F, Lebret LM, Moorrees CF. Natural head position and natural head orientation: basic considerations in cephalometric analysis and research. Eur J Orthod 1995;17:111-20.
28. Huggare JA. A natural head position technique for radiographic cephalometry. Dentomaxillofac Radiol 1993;22:74-6.
29. Houston WJ. Bases for the analysis of cephalometric radiographs: intracranial reference structures or natural head position. Proc Finn Dent Soc 1991;87:43-9.

Nostalgia Advertisement from a 1951 issue of the Journal