Original Article
https://doi.org/10.5115/acb.19.136
pISSN 2093-3665 eISSN 2093-3673
Anatomy & Cell Biology acb

Use of the orbito-occipital line as an alternative to the Frankfort line

Jung-Ah Park, Tae-Jun Ha, Je-Sung Lee, Wu-Chul Song, Ki-Seok Koh
Department of Anatomy, Research Institute of Medical Science, Konkuk University School of Medicine, Seoul, Korea

Abstract: Frankfort horizontal line, the line passing through the orbitale and porion, is one of the most widely used intracranial landmarks in cephalometric analysis. This study investigated the use of the orbito-occipital line extending from the orbitale to the external occipital protuberance as a novel horizontal line of the skull for substituting the Frankfort horizontal line. We evaluated the reproducibility of the new landmark and measured the angle between the orbito-occipital line and the Frankfort line. This study was conducted on 170 facial computed tomography (CT) scans of living adults from the Department of Plastic Surgery. After three-dimensionally reconstructed images were obtained from facial CT, the porion, orbitale, and external occipital protuberance were indicated by two observers twice. The angles between the orbito-meatal line (inferior orbital rim to porion; the Frankfort line) and the orbito-occipital line (inferior orbital rim to external occipital protuberance) were measured. There was no significant intraobserver or interobserver bias. The overall angle between the Frankfort line and orbito-occipital line was −0.5°±2.2° (mean±standard deviation). There was no statistically significant difference among side and sex. This study demonstrated good reproducibility of a new landmark—the external occipital protuberance—tested to replace the porion. The orbito-occipital line is a reliable, reproducible, and easily identifiable line, and has potential as a novel standard horizontal line to replace or at least supplement the Frankfort line in anthropological studies and certain clinical applications.

Key words: Frankfort plane, Orbito-meatal line, Orbito-occipital line, Computed tomography, Anatomy

Received June 19, 2019; Revised November 16, 2019; Accepted November 19, 2019

Introduction

Before the introduction of radiographic cephalometry by Broadbent [1], anthropologists had measured and recorded craniofacial structures using direct craniometric techniques. The introduction of the new x-ray technique by Broadbent [1] led to cephalometry being traditionally performed by using a standardized lateral and posteroanterior cephalogram [2]. Cephalometric analyses have been used for preoperative surgery planning, intraoperative surgery guidance, posttreatment follow-up, as well as archeological and anthropological studies [3, 4].

One of the most widely recognized intracranial landmarks in cephalometric research is the Frankfort horizontal plane, that was first introduced by Ihering in 1872 and established at an anthropological conference in Frankfort (or Frankfurt), Germany in 1884 in the so-called Frankfort Agreement [5]. It was defined as the plane passing through three points: the left orbitale and both porion points. The orbitale is the lowest point of the lower margin of the orbit, and the right and left porions are the uppermost points of the roof of each external acoustic opening. This plane has become accepted as the most reliable standard plane for use in craniofacial studies and orthodontics. In addition, the Frankfort horizontal plane is considered as the most repre-

Corresponding author:
Wu-Chul Song
Department of Anatomy, Konkuk University School of Medicine, 120 Neungdong-ro, Gwangjin-gu, Seoul 05029, Korea
Tel: +82-2-2030-7819, Fax: +82-2-2030-7845, E-mail: anatomy@kku.ac.kr

sentative of the true horizontal plane when the patient's head is in a natural position [6].

Cephalometric analysis is traditionally performed on two-dimensional (2D) radiographs obtained in posterior-anterior and lateral views. Although such plain radiographs have been widely used, they have inherent drawbacks since they provide only the 2D geometry of a three-dimensional (3D) anatomical structure. The associated limitations including magnification, distortion, and overlapping of anatomical structures lead to problems of accuracy, reliability, and reproducibility of landmark identification [7]. 3D cephalometric analysis using computed tomography (CT) has been introduced to replace 2D analysis with the aim of overcoming the aforementioned shortcomings and obtain more accurate cephalometric measurements [2, 8, 9]. Some studies have demonstrated the reproducibility and reliability of landmark identification of the porion and orbitale in 3D cephalometric analysis [10-12]. However, although the Frankfort line is the most commonly accepted reference line for use in cephalometric analysis, there have been a few attempts to propose novel landmarks aimed at overcoming the difficulties of identifying the intracranial landmark points used to define the Frankfort line [5, 13]. In addition, there may be a situation that the traditional Frankfort line cannot be used when there is a missing part of the skull or the porion of the temporal bone is fractured.

In this study we propose a new landmark, the external occipital protuberance, as a more easily identifiable external bony landmark and a relatively strong structure as a substitute for the porion. The purpose of this investigation was to determine the reproducibility of the orbito-occipital line as a novel reference line and measure the angle between this novel line and the standard Frankfort horizontal line. We further propose using the orbito-occipital line as an alternative line to the Frankfort horizontal line.

Materials and Methods

Facial CT images were retrospectively selected from patients hospitalized in the Department of Plastic Surgery at Konkuk University Chungju Hospital. We only included patients aged from 21 to 30 years to exclude aged bones since the skull may change or have deformation with aging process. Furthermore, subjects with a history of facial bone fracture or facial bone surgery were also excluded. The final sample of this study comprised 170 Korean adults (100 males and 70 females) aged 21–30 years, with a mean age of 25.1 years (Table 1). The present study was approved by the Ethics Committee of Konkuk University Chungju Hospital for data collection (approval No. KUCH 2018-04-013), and it was performed in accordance with the principles outlined in the Declaration of Helsinki.

Table 1. Subject distribution

Sex	Number	Mean age
Male	100	25.1
Female	70	24.6
Overall	170	24.9

Facial CT scans of the samples were obtained in transverse views with a slice thickness of 1 mm (Hispeed G; GE Healthcare, Niskayuna, NY, USA). These CT images were used to produce a 3D volumetric rendering of the skull using OnDemand software (Cybermed, Seoul, Korea). After 3D reconstruction, two observers indicated the positions of the landmarks twice. One of the observers was taking a master's degree course and the other was a master's degree candidate in the Department of Anatomy at Konkuk University. Detailed instructions for landmark identification were given to the two observers by the principal investigator prior to them making their observations.

Four landmark points were identified in the 3D reconstructed image, and so two lines were created. The orbito-meatal line (the Frankfort line) was created using the orbitale

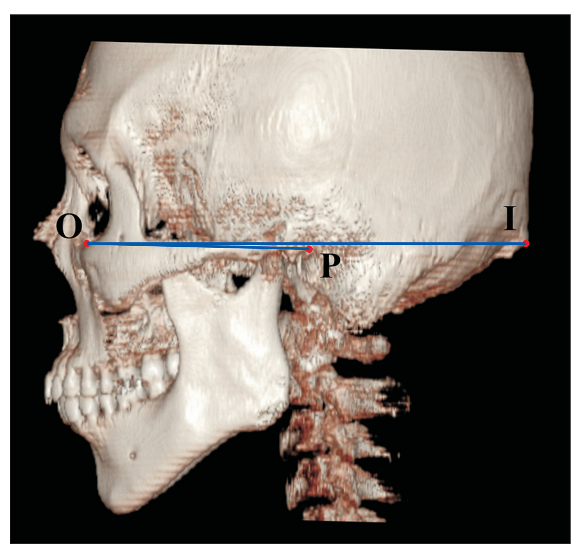

Fig. 1. The angle between the orbito-meatal line (the Frankfort horizontal line) from the orbitale (O) to the P and the orbito-occipital line from the O to the I of the external occipital protuberance on a three-dimensional volumetric rendering of the skull. I, inion; P, porion.

and porion on each side. The new landmark of the external occipital protuberance was chosen. We used the highest point of the external occipital protuberance, otherwise known as the inion. The orbito-occipital line was drawn passing through the inion and each orbitale (Fig. 1), and the angle between the orbito-occipital line and the Frankfort horizontal line was measured.

The intraobserver and interobserver reproducibilities of the angle measurements as well as side-related and sex-related differences were determined using *t*-test. All data analysis was performed using IBM SPSS Statistics for Windows, Version 24.0 (IBM Co., Armonk, NY, USA). The cutoff for statistical significance was set at $P<0.05$.

Results

The angle between the Frankfort line and the orbito-occipital line is summarized in Table 2 according to sex and side. The overall angle between the two lines was –0.5°±2.2° (mean±standard deviation). The negative mean value means that the porion is located under the orbito-occipital line. Four datasets were acquired by two observers. Intraobserver and interobserver agreement of the four datasets were analyzed and there was no statistically significant intrapersonal or interpersonal bias ($P>0.05$). The angle did not differ with sex or side ($P>0.05$).

The distribution of the angle between the Frankfort line and the orbito-occipital line is presented in Table 3 and Fig. 2. The angle was between –1° and 1° in 37.1% of cases and between –3° and 3° in 83.0%. Photographic examples of negative, average, and positive angles are shown in Fig. 3.

Discussion

A reliable reference landmark is an essential component of cephalometric analyses for orthodontic diagnosis, treat-

Table 2. Angle between Frankfort line and orbito-occipital line

Sex	Right (°)	Left (°)	Overall (°)
Male	–0.4±2.2	–0.5±2.4	–0.5±2.3
Female	–0.6±2.0	–0.5±2.0	–0.5±2.1
Overall	–0.5±2.1	–0.5±2.3	–0.5±2.2

Table 3. Distribution of angle between Frankfort line and orbito-occipital line

Range (°)	Female (n=140)	Male (n=200)	Overall (n=340)
<–3	15 (10.7)	31 (15.5)	46 (13.5)
–3~–1	42 (30.0)	43 (21.5)	85 (25.0)
–1~1	53 (37.9)	73 (36.5)	126 (37.1)
1~3	25 (17.9)	46 (23.0)	71 (20.9)
>3	5 (3.6)	7 (3.5)	12 (3.5)

Values are presented as number (%).

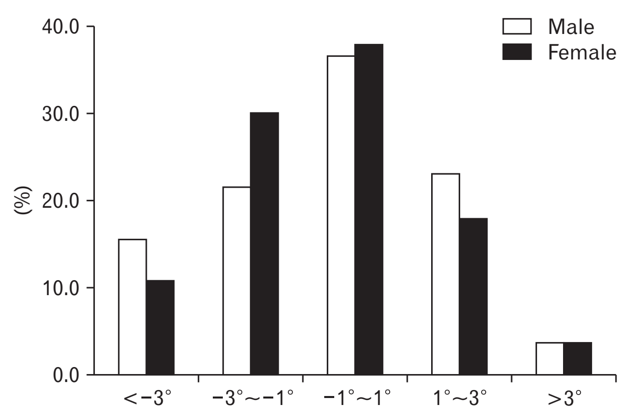

Fig. 2. Distribution of the angle between the Frankfort line and the orbito-occipital line according to sex.

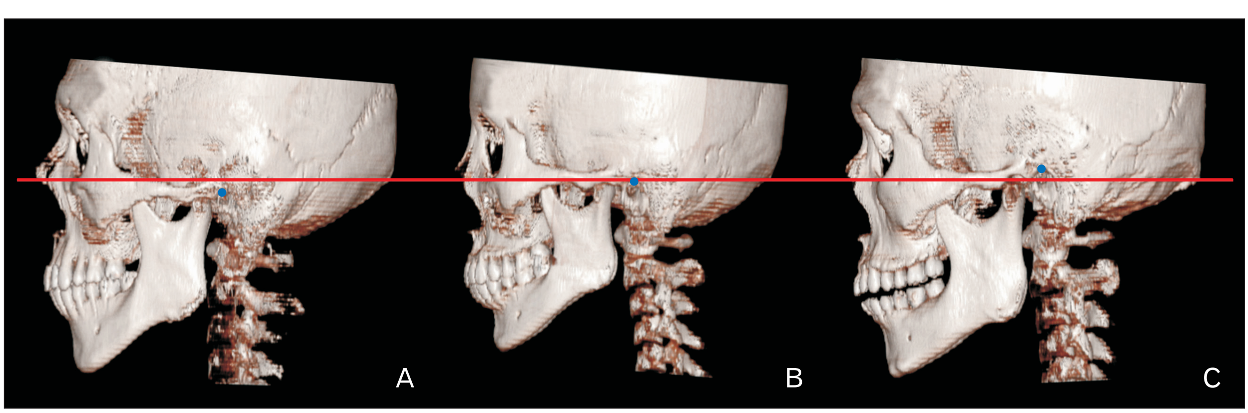

Fig. 3. Examples of the relationship between the Frankfort line and the orbito-occipital line: (A) negative angle, (B) average angle, and (C) positive angle. Line: orbito-occipital line.

https://doi.org/10.5115/acb.19.136

ment planning, posttreatment evaluation, and anthropological studies. Many reference planes have been used, including the Frankfort horizontal plane, mid-sagittal plane, sella-nasion plane, and facial plane [14]. Most of these planes are defined based on intracranial anatomical points, and the Frankfort horizontal plane has been the most widely used standard horizontal plane for reflecting the natural head position [4]. However, the reliability and reproducibility of this plane have been questioned in several studies [4, 15], with some authors pointing out that the intracranial landmarks for defining the Frankfort horizontal plane (especially the porion) are difficult to identify. Possible errors in identifying the porion due to considerable variations in the position and inclination of the external acoustic meatus and in the size of the external acoustic orifice have been reported [13]. Ludlow et al. [16] compared the accuracy of cephalometric landmark identification in conventional lateral views and cone-beam CT, and reported that the precision of the porion position was worse in multiplanar reconstructed images than for other landmarks. Hassan et al. [17] also pointed out that the porion was the most imprecise landmark because of the curvature of the external acoustic meatus leading to difficulty in identifying the most-superior point of the external acoustic orifice. This prompted Pittayapat et al. [5] to suggest using the internal acoustic foramen as an alternative to replace the porion; those authors demonstrated that the angle between the Frankfort plane and a new plane connecting each orbitale and the mid-internal acoustic foramen was less than 1°. We have introduced the external occipital protuberance for the first time in this study as a new landmark to replace the porion.

The external occipital protuberance has been frequently discussed in anthropology, and has commonly been used in human sexual dimorphism studies [18-20]. The external occipital protuberance was chosen as a novel landmark in the present study since it is an external bony landmark that provides good visualization and reproducibility. We used the highest point of the external occipital protuberance that is also referred to as the inion and the line passing through the inion and each orbitale was drawn. This study found that the angle between the orbito-occipital line and the Frankfort horizontal line was less than 1° on average, which would not be clinically significant, and ranged from only –3° to 3° in 83.0% of cases. This means that the line passing through the external occipital protuberance and each orbitale is almost parallel to the traditional Frankfort line, and so it can be applied in both clinical and anthropological studies. The orbito-occipital line could be especially useful in cases of temporal bone fracture when the porion cannot be used as a landmark for the Frankfort line. Moreover, in anthropological and archeological studies, the orbito-occipital line can at least supplement the use of the Frankfort horizontal line when part of the skull is fractured or missing, because the external occipital protuberance is a relatively strong structure.

Cephalometric analysis was conventionally performed using 2D radiographs, but it has been moving toward utilizing 3D imaging modalities such as cone-beam CT in order to achieve accurate and reproducible cephalometric measurements [16, 21, 22]. Hassan et al. [17] showed that adding multiplanar reconstructed images to a 3D surface model the increased intraobserver and interobserver agreements and the accuracy of identifying landmarks [17]. In recent studies, automatic cephalometric landmark plotting using multiplanar reconstructed images was proposed to replace manual landmark identification for improving the accuracy and reliability [22-24]. Using the external occipital protuberance as an easily identifiable alternative to the porion is expected to be useful in computerized automatic plotting as well, although this needs to be confirmed in future studies involving larger samples.

The samples in this retrospective study did not represent people of all ages since they were selected from the facial CT scans of patients ranged from 21 to 30 years only. However, because many bony landmarks including the external occipital protuberance can be deformed during the aging process, the results obtained in the present study might be more accurate and reliable due to the inclusion of young subjects only. However, further research including elderly bones will be needed to confirm that this novel landmark can be applied to aged people as well. Another limitation of this study is that we used the orbito-meatal and orbito-occipital lines instead of planes in the 3D analysis. However, radiography is still the gold standard in cephalometric analysis for clinical use despite the increasing use of CT. We considered that using lines instead of planes was more convenient and easier for application and lines could be representative of planes if it there were no significant asymmetry. Furthermore, we evaluated both sides of the orbito-meatal and orbito-occipital lines and measured the angle between the two lines on each side.

In conclusion, the Frankfort line is commonly used as a standard horizontal line for cephalometric analysis in orthodontics and anthropological studies. The present study investigated the potential of using a new landmark, the external occipital protuberance, to replace the porion. The novel horizontal orbito-occipital line shows good reproducibility and so has potential to substitute or at least supplement the standard Frankfort horizontal line in anthropological studies and certain clinical applications.

ORCID

Jung-Ah Park: https://orcid.org/0000-0003-0524-1076
Tae-Jun Ha: https://orcid.org/0000-0003-1192-8456
Je-Sung Lee: https://orcid.org/0000-0003-0863-641X
Wu-Chul Song: https://orcid.org/0000-0001-9678-1830
Ki-Seok Koh: https://orcid.org/0000-0003-2861-4031

Author Contributions

Conceptualization: WCS. Data acquisition: JAP, TJH, JSL. Data analysis or interpretation: JAP, WCS. Drafting of the manuscript: JAP, WCS. Critical revision of the manuscript: WCS, KSK. Approval of the final version of the manuscript: all authors.

Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

References

1. Broadbent BH. A new X-ray technique and its application to orthodontia. Angle Orthod 1931;1:45-66.
2. Devereux L, Moles D, Cunningham SJ, McKnight M. How important are lateral cephalometric radiographs in orthodontic treatment planning? Am J Orthod Dentofacial Orthop 2011; 139:e175-81.
3. Chaconas SJ, Fragiskos FD. Orthognathic diagnosis and treatment planning: a cephalometric approach. J Oral Rehabil 1991; 18:531-45.
4. Lundström A, Lundström F. The Frankfort horizontal as a basis for cephalometric analysis. Am J Orthod Dentofacial Orthop 1995;107:537-40.
5. Pittayapat P, Jacobs R, Bornstein MM, Odri GA, Lambrichts I, Willems G, Politis C, Olszewski R. Three-dimensional Frankfort horizontal plane for 3D cephalometry: a comparative assessment of conventional versus novel landmarks and horizontal planes. Eur J Orthod 2018;40:239-48.
6. Lundström A, Lundström 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.
7. Chien PC, Parks ET, Eraso F, Hartsfield JK, Roberts WE, Ofner S. Comparison of reliability in anatomical landmark identification using two-dimensional digital cephalometrics and three-dimensional cone beam computed tomography *in vivo*. Dentomaxillofac Radiol 2009;38:262-73.
8. Chen YJ, Chen SK, Chang HF, Chen KC. Comparison of landmark identification in traditional versus computer-aided digital cephalometry. Angle Orthod 2000;70:387-92.
9. Olszewski R, Zech F, Cosnard G, Nicolas V, Macq B, Reychler H. Three-dimensional computed tomography cephalometric craniofacial analysis: experimental validation *in vitro*. Int J Oral Maxillofac Surg 2007;36:828-33.
10. Pittayapat P, Limchaichana-Bolstad N, Willems G, Jacobs R. Three-dimensional cephalometric analysis in orthodontics: a systematic review. Orthod Craniofac Res 2014;17:69-91.
11. Olszewski R, Tanesy O, Cosnard G, Zech F, Reychler H. Reproducibility of osseous landmarks used for computed tomography based three-dimensional cephalometric analyses. J Craniomaxillofac Surg 2010;38:214-21.
12. Schlicher W, Nielsen I, Huang JC, Maki K, Hatcher DC, Miller AJ. Consistency and precision of landmark identification in three-dimensional cone beam computed tomography scans. Eur J Orthod 2012;34:263-75.
13. Kattan EE, Kattan ME, Elhiny OA. A new horizontal plane of the head. Open Access Maced J Med Sci 2018;6:767-71.
14. Ryu HK, Chong HJ, An KY, Kang KH. Short-term and long-term treatment outcomes with Class III activator. Korean J Orthod 2015;45:226-35.
15. Madsen DP, Sampson WJ, Townsend GC. Craniofacial reference plane variation and natural head position. Eur J Orthod 2008;30:532-40.
16. Ludlow JB, Gubler M, Cevidanes L, Mol A. Precision of cephalometric landmark identification: cone-beam computed tomography vs conventional cephalometric views. Am J Orthod Dentofacial Orthop 2009;136:312.e1-10; discussion 312-3.
17. Hassan B, Nijkamp P, Verheij H, Tairie J, Vink C, van der Stelt P, van Beek H. Precision of identifying cephalometric landmarks with cone beam computed tomography *in vivo*. Eur J Orthod 2013;35:38-44.
18. Veyre-Goulet SA, Mercier C, Robin O, Guérin C. Recent human sexual dimorphism study using cephalometric plots on lateral teleradiography and discriminant function analysis. J Forensic Sci 2008;53:786-9.
19. Gülekon IN, Turgut HB. The external occipital protuberance: can it be used as a criterion in the determination of sex? J Forensic Sci 2003;48:513-6.
20. Casado AM. Quantifying sexual dimorphism in the human cranium: a preliminary analysis of a novel method. J Forensic Sci 2017;62:1259-65.

https://doi.org/10.5115/acb.19.136

21. Olmez H, Gorgulu S, Akin E, Bengi AO, Tekdemir I, Ors F. Measurement accuracy of a computer-assisted three-dimensional analysis and a conventional two-dimensional method. Angle Orthod 2011;81:375-82.
22. Rossini G, Cavallini C, Cassetta M, Barbato E. 3D cephalometric analysis obtained from computed tomography. Review of the literature. Ann Stomatol (Roma) 2011;2:31-9.
23. Gupta A, Kharbanda OP, Sardana V, Balachandran R, Sardana HK. Accuracy of 3D cephalometric measurements based on an automatic knowledge-based landmark detection algorithm. Int J Comput Assist Radiol Surg 2016;11:1297-309.
24. Shahidi Sh, Oshagh M, Gozin F, Salehi P, Danaei SM. Accuracy of computerized automatic identification of cephalometric landmarks by a designed software. Dentomaxillofac Radiol 2013;42:20110187.