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ORIGINAL ARTICLE

# Using the zygomatic arch as a reference line for clinical applications and anthropological studies

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## Abstract

**Purpose** The Frankfurt line is the most frequently and widely used reference line in cephalometric analysis, but has shortcomings including the difficulty of landmark identification. This study investigated using the superior border of the zygomatic arch as a new external bony landmark, including measuring the angle between the new reference line and the Frankfurt line.

**Methods** Facial computed tomography scans were obtained from 170 patients (100 males and 70 females) hospitalized at Konkuk University Chungju Hospital. After three-dimensional reconstruction, the locations of the porion and the inferior orbital rim and the superior border of the zygomatic arch were identified twice by two observers using software. A horizontal line parallel to the superior border of the zygomatic arch was established. The angle between the Frankfurt line and new reference line was then measured on each side.

**Results** There was no significant intraobserver or interobserver bias. The angle between the Frankfurt line and the superior border of the zygomatic arch was 4.5° ± 2.5° (mean ± SD), and it was somewhat larger in females than males, but the difference was not statistically significant.

**Conclusions** This study demonstrated the good reproducibility of the location of the superior border of the zygomatic arch and found that the angle between the new reference line and the Frankfurt line is relatively constant. The superior border of the zygomatic arch therefore has potential as an alternative reference line to the Frankfurt line in specific clinical applications and anthropological studies, since it is a more accessible bony landmark on the external skull.

**Keywords** Frankfurt plane · Zygomatic arch · Anatomy · Anthropology · Computed tomography · Face · Reference line

## Introduction

A cephalometric analysis is widely used in clinical applications such as orthodontic diagnosis, orthognathic surgery, or neurosurgery planning as well as in anthropological studies [2, 8]. One of the important anatomical landmarks of the skull when performing a cephalometric analysis is the Frankfurt horizontal line. This line (and also the Frankfurt plane) was first introduced by von Ihering in 1872, and it passes through the center of the external auditory meatus (porion) to the lowest point of the inferior margin of each orbit [12]. The Frankfurt agreement at the World Congress of Anthropology (in Frankfurt, Germany in 1882) then modified its definition, so that the plane now passes the top of the porion to the lowest point of the orbit (orbitale). This anatomical line is known to closely approximate the true horizontal when a person's head is in a natural position [9, 14].

A cephalometric analysis is conventionally performed using two-dimensional (2D) methods, including the acquisition of plain lateral and frontal cephalograms [3]. However, traditional 2D analysis has revealed several drawbacks, including the superimposition of structures causing errors in landmark identification and the difficulty in reproducing the head position [1, 5, 10]. Three-dimensional (3D) cephalometric analysis using computed tomography (CT) is now replacing 2D analysis due to these limitations [11, 13, 15].

The accuracy and reliability of the Frankfurt line has been questioned in several studies, although it is still the most commonly accepted standard reference line for cephalometry [4, 7, 17]. Furthermore, identifying the Frankfurt line is difficult due to the uncertainty of the locations of the two internal reference

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points, which has led to a few studies proposing new landmarks as substitutes for the Frankfurt plane [6, 12, 19]. When considering a reference line as a substitute for the Frankfurt line, stable, reproducible, and easily approachable landmarks need to be chosen. We suggest the superior border of the zygomatic arch—which is more easily accessible bony landmark of the external skull—as a new reference line to replace the Frankfurt line for use in clinical applications and anthropological studies.

The principal objective of this investigation was to determine the reproducibility of superior border of the zygomatic arch and characterize the angle between the new reference line and the traditional Frankfurt line.

## Materials and methods

Facial CT images were retrospectively selected from the patients hospitalized in Konkuk University Chungju Hospital, Department of Plastic surgery. Only subjects with an age range of 21–30 years were included in this study to exclude aged bones and subjects with history of facial bone fracture and surgery were excluded. Finally, the sample of this study consisted of 170 young aged Korean adult patients (100 males and 70 females) with an age range of 21–30 years. The mean age of the subjects was 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 2018-04-012), and it was performed in accordance with the principles outlined in the Declaration of Helsinki.

Serial facial CT images of the subjects were acquired in transverse views with a slice thickness of 1 mm (Hispeed G, GE Healthcare, Niskayuna, NY, USA). These CT images were reconstructed into a 3D volumetric rendering of the skull using OnDemand software (Cybermed, Seoul, Korea). After the reconstruction, the Frankfurt line was drawn on each side using two points: the inferior border of the orbital rim and the superior border of the porion. The superior border of the zygomatic arch was chosen as a new reference line in this study, and the angle between the Frankfurt line and the superior border of the zygomatic arch was measured (Fig. 1). The superior border of the zygomatic arch was usually flat and there was no difficulty in measuring the angle between the zygomatic arch and the Frankfurt line in such cases. However, there were some cases of an uneven superior border of the zygomatic arch. In those cases, each starting points going upward on a curvy surface were chosen, and they were connected to create a line.

**Table 1** Subject distribution

| Sex | *N* | Mean age |
|---|---|---|
| Male | 100 | 25.1 |
| Female | 70 | 24.6 |
| Overall | 170 | 24.9 |

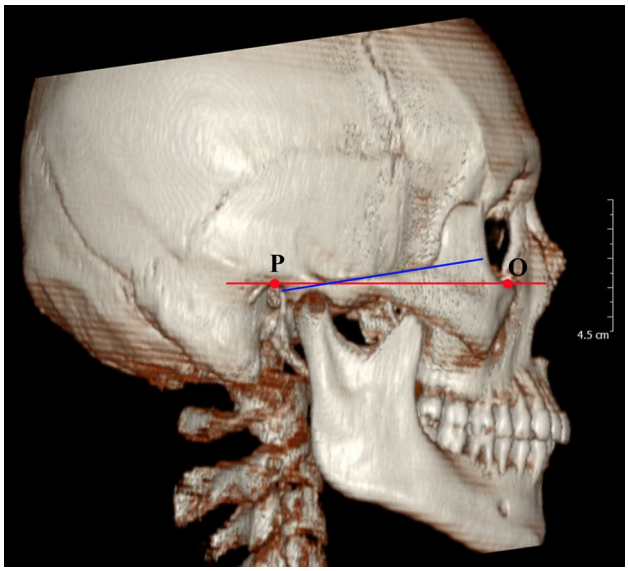


**Fig. 1** This study measured the angle between the red line, which is the Frankfurt line from the porion (P) to the inferior orbital margin (IOM), and the blue line, which is the superior border of the zygomatic arch on a three-dimensional volumetric rendering of the skull. (Color figure online)

Each of two observers (master's degree course and master's degree candidate in Department of Anatomy in Konkuk University) measured the angle twice. Detailed instructions for landmark identification were given to two observers prior to the observation.

The intraobserver and interobserver reproducibility of angular measurement as well as side-related and sex-related differences were performed using the Student's *t* test. All data analyses were performed using the Statistical Package of Social Sciences for Windows, version 24 (SPSS Statistics, IBM, Chicago, IL, USA). The cutoff for statistical significance was $p < 0.05$.

## Results

The superior border of the zygomatic arch is usually flat, but in some cases it can be uneven. We set two points in cases with an uneven superior border, which were the starting points going from straight to upward. There was no intrapersonal or interpersonal bias ($p > 0.05$), and so the four data set were pooled, averaged, and analyzed. The angle between the Frankfurt line and the superior border of the zygomatic arch was measured, and is listed in Table 2 according to the sex and the side.

The angle appeared to be somewhat larger in females than in males (Fig. 2), but the difference was not statistically significant ($p > 0.05$). There were also no differences between the right and left sides ($p > 0.05$). The

**Table 2** Mean angular measurement with standard deviation between the Frankfurt line and the superior border of zygomatic arch

| Sex | Right | Left | Overall |
|---|---|---|---|
| Male | 4.3 ± 2.6 | 4.1 ± 2.7 | 4.2 ± 2.6 |
| Female | 4.8 ± 2.3 | 4.8 ± 2.3 | 4.8 ± 2.3 |
| Overall | 4.5 ± 2.5 | 4.4 ± 2.5 | 4.5 ± 2.5 |

Unit: degree

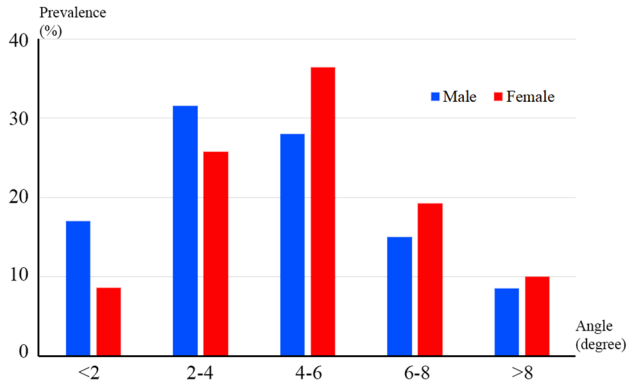


**Fig. 2** Distribution of the angle between the Frankfurt line and superior border of the zygomatic arch according to sex

overall angle was 4.5° ± 2.5° (mean ± SD), and it ranged from − 3.3° to 11.9°. A positive value means that the angle of the anterior part was larger than that of posterior part, and the value was negative in 14 cases of 340 sides (4.1%). Photographic examples of small, average and large angles are shown in Fig. 3.

## Discussion

The Frankfurt line has been considered a reliable reference horizontal line that provides the best anatomical indicator of the true horizontal line for decades [8]. It is commonly used for patient head positioning, the diagnosis and treatment planning of orthodontic and orthognathic surgery, and anthropological cephalometric analysis. However, this reference line has some drawbacks for use as a standard, such as potential variability and difficulties in finding the locations of the two internal reference points. Some researchers have therefore suggested using another line or plane as a substitute for the Frankfurt line. Sassouni proposed the "optic plane" that bisects the supraorbital and infraorbital planes as a new reference plane, because it was based on more easily identifiable bony structures [19]. Pittayapat et al. suggested the internal acoustic foramen (IAF) as a new landmark to replace the porion, since it shows good reproducibility [12]. The mean angle between the new plane (right orbitale–left orbitale–mid-IAF) and the Frankfurt line was less than 1°, which demonstrated its potential as a new landmark. The present study chose the superior border of the zygomatic arch as a new landmark for the first time. This landmark was selected since its location is easier to identify than the traditional one and was thought to be reproducible and reliable.

Although the superior border of the zygomatic arch was flat in most cases, there were some cases of an uneven superior border of the zygomatic arch. In those cases, identifying landmarks on a curved anatomical area can be somewhat subjective and hence lead to unreliable results. However, this study found that there was no significant intraobserver or interobserver bias regarding the superior border of the zygomatic arch. Hassan et al. showed that adding multiplanar reformation (MPR) images to 3D surface models increased the accuracy of identifying

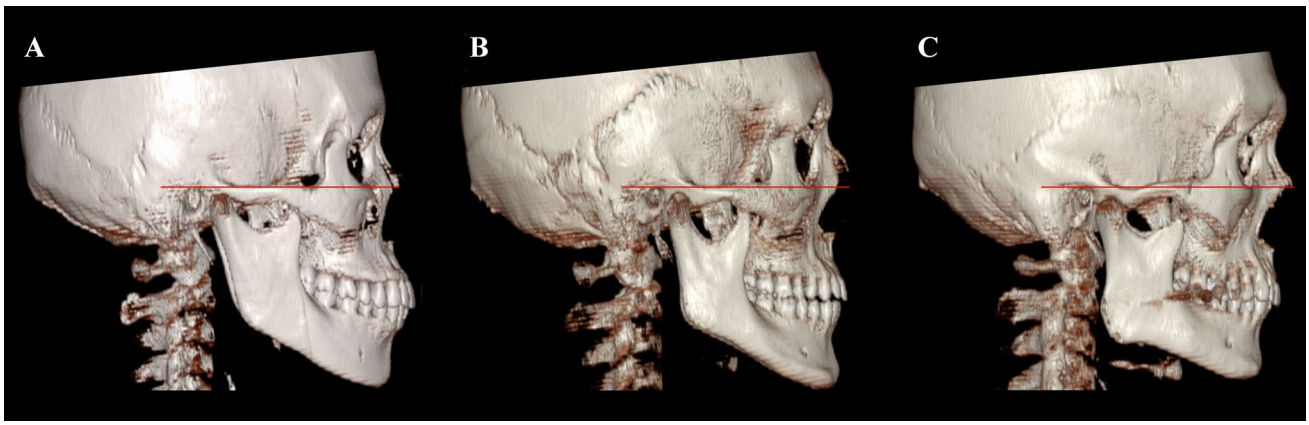


**Fig. 3** Examples of various angles between the Frankfurt line (red line) and the superior border of the zygomatic arch: **a** small, **b** average, and **c** large. (Color figure online)

cephalometric landmarks and reduced intraobserver and interobserver bias. Future studies that include the use of MPR images should therefore be performed [4].

In a group of 170 subjects aged 21–30 years, we found that the angle between the superior border of the zygomatic arch and the Frankfurt line was 4.5° ± 2.5° and ranged from − 3.3° to 11.9° (Table 2). However, the ages of the subjects included in this study group meant that they would not be representative of people of all ages, since the samples were selected from the facial CT scans of patients hospitalized in the Konkuk University Chungju Hospital. The zygomatic arch shows age-related changes, with posterior and anterior remodeling and an increasing temporal fossa [18, 20].

Future studies should also be performed with larger samples. The superior border of the zygomatic arch showed a mean upward tip anteriorly of + 4.5°, which means that we can also determine the position of the Frankfurt line based on the line of the superior border of the zygomatic arch. This would be potentially beneficial for clinical applications or anthropological studies in cases where the Frankfurt line cannot be used as a reference line, such as in fractures of the orbital rim or temporal bone. The results of the present study can be used for topographic anatomical studies or clinical applications involving small areas. For example, because the superior border of the zygomatic arch is relatively stable, when the temporal branch of the facial nerve crosses the zygomatic arch, the angle between these two structures can be measured.

It is widely accepted that humans are sexually dimorphic [18]. Schlager et al. evaluated sex-related differences in the zygomatic structure and reported that the zygomatic arch is more bowed laterally and forms a more acute angle with the temporal and zygomatic bone in males than in females [16]. The present study found that the angle between the Frankfurt line and the superior border of the zygomatic arch was somewhat larger in females than in males, which is consistent with that previous report, but this difference was found not to be statistically significant in this study.

The Frankfurt line is routinely used as an anatomical reference line for diagnosis and surgery planning in orthodontics and for cephalometric analysis in anthropological studies. However, its potential variability and difficulty in finding landmarks render it subject to errors. The present study has found that the superior border of the zygomatic arch is an external bony landmark that shows good reproducibility and appears at a relatively constant angle to the traditional Frankfurt line, and hence it can potentially be used as a reference line in clinical applications and anthropological studies.

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