The anatomy of the sphenoid sinus and pterygomaxillary junction region in Le Fort I osteotomy

Koichiro Ueki (✉ kueki@yamanashi.ac.jp)
University of Yamanashi

Kunio Yoshizawa
University of Yamanashi

Akinori Moroi
University of Yamanashi

Research Article

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Abstract

Purpose.

The purpose of this study was to examine the location and morphology of sphenoid sinus, pterygoid plate and great palatine canal at the pterygomaxillary region in Le Fort I osteotomy.

Method.

The subjects consisted of 144 Japanese patients with jaw deformity patients. Lateral cephalograms and computed tomography (CT) were analyzed for all patients. The measurements of the sphenoid sinus, pterygoid plate and great palatine canal were assessed using 2 bilateral sagittal planes (right and left) involving the great palatine canals and mid-sagittal plane involving ANS and PNS.

Results.

The subjects were divided into three groups (47 class II female, 62 class III female and 35 class III male). Sphenoid sinus existed on the sagittal plane involving the great palatine canal in 81 of 94 sides (86.2%) in class II female, 85 of 124 sides (68.5%) in class III female and 57 of 70 sides (81.4%) male. The distribution was significant difference (P = 0.0386). There was significant difference in the right maxillary sinus length (ML) between class II female and class III female (P = 0.0049). Ramus inclination in cephalometric measurements was selected as a variable related to the vertical distance between the sphenoid sinus wall and PNS (VDS) by stepwise regression analysis (P = 0.003 right, P = 0.0210 left).

Conclusions.

These results suggest that the sphenoid sinus exist more frequently recognized close to superior site of the pterygoid plate in class II female. However, the location of the sphenoid sinus at the pterygomaxillary junction region could not be predicted accurately using cephalometric measurements analysis.

Introduction.

Le Fort I osteotomy is frequently used to correct dentofacial deformities, in combination with other mandibular osteotomies such as sagittal split ramus osteotomy and genioplasty. Although the complications after Le Fort I osteotomy was comparatively few, the rates varied from 4 to 9% [1–5]. The complications included relapse, neurosensory disturbance, loss of teeth vitality, sinusitis, necrosis, hemorrhagic event, nasal septal deviation, unfavorable fracture and infection [2–8]. These may not be life threatening, however rare ones such as blindness or deep vein thrombosis might be major and fatal [6, 8, 9]. Furthermore, unusual complications such as cerebrospinal fluid leak, fracture of the clivus and delayed bleeding of sphenopalatine artery can also occur [10, 11].
In particular, the previous report revealed obviously that maxillary setback with impaction movement presented the highest rate of complications compared to maxillary movement types [5]. This might be due that more complicated operation was performed at the pterygomaxillary region. In the cases of maxillary setback or impaction, resection of the maxillary tuberosity or pterygoid plate is necessary to remove the bony interference between the maxilla and the pterygoid plate. As the maxillary tuberosity removal technique, several methods and devices have been developed to avoid the pterygoid plate fracture, damages to the maxillary artery and the branches such as descending palatine artery or skull base including important vessels and nerves [12–15]. On the other hand, the intentional pterygoid plate fracture by sagittal saw, chisel or ultrasonic bone curette have been advocated to remove the bony interference [16–21].

The pterygoid plate arises from the base of the sphenoid bone and forms the posterior border of the pterygopalatine fossa. The third portion of the maxillary artery enters through the pterygopalatine fossa and gives off several branches [22]. The sphenoid sinus was located at the center of the base of skull. This anatomic sinus was in close relationship by numerous neurovascular structures including cavernous sinus, internal carotid artery, intracranial structures, cranial nerves II to VI, and pituitary gland [23]. Vascular or neurological complications are rare but can lead to permanent disability or even death. Therefore, it is very important for the orthognathic surgeons to know the anatomy of the region.

The sphenoid sinus can exist at the superior site of not only nasal cavity but also the pterygoid plate. Especially, when the intentional pterygoid plate fracture is performed to remove the bony interference, the anatomy should be paid attention. However, there were few reports regarding the anatomy of this region in Japanese jaw deformity patients. Furthermore, no report was found regarding the relation between lateral and frontal skeletal morphology and structure of the sphenoid sinus and pterygomaxillary region.

The purpose of this study was to examine the location and morphology of sphenoid sinus, pterygoid plate and great palatine canal at the pterygomaxillary region to avoid various complications such as blood loss, nerve injury, blindness and sphenoid sinus perforation in Le Fort I osteotomy with and without intentional pterygoid plate fracture.

**Patients And Methods**

**Patients**

The subjects were 144 Japanese adults with jaw deformities who underwent orthognathic surgery from 2012 to 2019. The subjects were divided into three groups (class II female, class III female and class III male). The exclusion criteria were a history of previous orthognathic or facial (reconstructive) surgery, craniofacial (congenital) abnormality. This study was a retrospective study and was approved by the ethical committee of the Clinical Study of Yamanashi University Hospital. Informed consent was obtained from all patients.

**Cephalogram assessment**
All patients underwent lateral and frontal cephalograms to assess the skeletal pattern. Cephalometric measurements were SNA, SNB, ANB, Gonial angle, Ramus inclination to FH (Frankfurt horizontal plane), Occlusal plane to FH, Occlusal plane to SN (Sella to Nasion), Mandibular length (Condylion to Gnathion), Incisor overjet and Incisor overbite, and Mx-Md midline (the angle between the ANS-Menton line and the line perpendicular to the bilateral zygomatic frontal suture line)[24, 25].

**CT assessment**

A high-speed, advantage-type CT generator (Aquilion One, Toshiba Medical Systems Corp., Tochigi, Japan) was used, similarly to a previously reported method [26, 27]. The measurements of the sphenoid sinus and pterygoid plate, great palatine canal were assessed using 4 images that were 2 side-sagittal planes (right 144 sides and left 144 sides) involving the great palatine canals, mid-sagittal plane (144 cases) involving ANS and PNS and coronal plane (144 cases) involving the midpoint between Sella and PNS parallel to FH plane.

At first, number of the sides that sphenoid sinus existed on the side-sagittal plane involving the great palatine canal was counted and it was examined whether the rates was significantly difference among the groups.

The length, angle and square were calculated using an image software (Image J®; the Research Services Branch, National Institute of Mental Health, Bethesda, MD) and SimPlant O & O (Materialise Dental n.v., Leuven, Belgium) (Figs. 1–3).

Measurements on the mid-sagittal plane involving ANS and PNS

The midline between Sella and PNS perpendicular FH plane was determined as a reference line (SP line)

1. HS: Height of sphenoid sinus on the SP line, on the mid-sagittal plane
2. APS: Antero-posterior length of sphenoid sinus parallel to FH, on the mid-sagittal plane
3. HDS: Horizontal distance between the SP line and PNS, on the mid-sagittal plane
4. VDS: Vertical distance between the sphenoid sinus wall on the SP line and PNS, on the mid-sagittal plane
5. SSm: Square of sphenoid sinus on the mid-sagittal plane

Measurements on the coronal plane involving the midpoint between Sella and PNS parallel to FH plane.

1. WS: Maximum width of sphenoid sinus on the coronal plane involving the SP line
2. SSC: Square of sphenoid sinus on the coronal plane involving the SP line

Measurements on the side-sagittal plane involving the great palatine canals

In the sides that the sphenoid sinus was recognized on the side-sagittal plane involving the great palatine canal, the following items were measured on the right and left sides.
1. HS right and left: Height of sphenoid sinus on the SP line, on the side-sagittal plane
2. APS right and left: Antero-posterior length of sphenoid sinus parallel to FH on the side-sagittal plane
3. HDS right and left: Horizontal distance between the SP line and the posterior wall of maxilla, on the side-sagittal plane
4. VDS right and left: Vertical distance between the sphenoid sinus wall on the SP line and PNS, on the side-sagittal plane
5. SS right and left: Square of sphenoid sinus on the side-sagittal plane
6. ML right and left: Distance between anterior wall and posterior wall of maxillary sinus at the PNS plane level (parallel to FH plane), on the side-sagittal plane
7. MSD right and left: Distance between anterior wall at the PNS plane level (parallel to FH plane) and sphenoid sinus wall, on the side-sagittal plane

To determine the reliability of lateral cephalogram measurements and CT measurements, a sample of 10 patients was randomly selected and their images were analyzed again after a 1-month interval. Intraclass correlation coefficients (ICCs) were calculated to assess the intra-observer reliability of the measurements. The ICCs were > 0.95, indicating high consistency and reproducibility.28

After surgery, in the cases who underwent Le Fort I osteotomy with intentional pterygoid plate fracture, sinus perforation was examined.

**Statistical analysis**

Data were statistically analyzed using IBM SPSS Statistics version 26 (Japan IBM Corp., Tokyo, Japan).

The Shapiro-Wilk test was used to examine the normal distribution of the data. Comparisons among classes II female, class III female and class III male were performed using Scheffe's test. Comparison between right and left was performed paired t-test. The distribution of sides that the sphenoid sinus existed on the sagittal plane involving the great palatine canal was examined using chi squared test. Stepwise regression analysis was then performed to examine whether the distance to the sphenoid sinus could be predicted from the results of cephalometric measurements. Differences were considered significant at P < 0.05.

**Results**

The participants were 144 Japanese adults (288 sides) with jaw deformities who underwent orthognathic surgery. At the time of orthognathic surgery, the patients ranged in age from 16 to 53 years (mean age, 25.8 years; standard deviation, 8.6 years). The subjects were divided into three groups (47 class II female, 62 class III female and 35 class III male).

Sphenoid sinus existed on the sagittal plane involving the great palatine canal in 81 of 94 sides (86.2%) in class II female, 85 of 124 sides (68.5%) in class III female and 57 of 70 sides (81.4%) male. The
distribution was significant difference ($P = 0.0386$) (Table 1).

## Cephalometric analysis

There were significant differences between classes II female and III female in the SNB ($P < 0.0001$), ANB ($P < 0.0001$), Ramus inclination ($P < 0.0001$), Occlusal plane to FH ($P = 0.0088$), Occlusal plane to SN ($P = 0.0006$), mandibular length ($P = 0.0006$), and Overjet ($P < 0.0001$) (Table 1). Furthermore, there were significant differences between classes II female and class III male in the SNA ($P = 0.0472$), SNB ($P < 0.0001$), ANB ($P < 0.0001$), Ramus inclination ($P < 0.0001$), Occlusal plane to FH ($P < 0.0001$), Occlusal plane to SN ($P < 0.0001$), mandibular length ($P < 0.0001$), and Overjet ($P < 0.0001$) (Table 2).

## Assessment on the mid-sagittal plane and coronal plane

There was significant difference between class III female and class III male in the HS ($P = 0.0381$), VDS ($P = 0.0023$) and WS ($P = 0.0423$). There was significant difference between class II female and class III male in the VDS ($P = 0.0028$). However, there was no significant differences between class II female and class III female in all measurements on the mid-sagittal plane and coronal plane (Table. 3).

## Assessment on the side-sagittal plane

Next, the cases whose sphenoid sinus existed on the side-sagittal plane involving the great palatine canal on both sides were selected and they were divided into 3 groups (36 Class II female, 36 Class III female and 26 Class III male).

There was no difference between right and left in all measurements. Furthermore, there was no difference between deviation and non-deviation side in all measurements, according to the Mx-Md midline.

The distance between anterior wall and posterior wall of maxilla at the PNS plane level (parallel to FH plane) on the sagittal plane involving the great palatine canal (maxillary sinus length: ML) were right $30.4 \pm 3.5$ mm and left $30.3 \pm 3.0$ mm in class II female, right $27.9 \pm 2.6$ mm and left $28.3 \pm 2.8$ mm in class III female and right $29.2 \pm 3.5$ mm and left $29.1 \pm 3.1$ mm in class III male. There was significant difference in the right ML between class II female and class III female ($P = 0.0049$).

However, there were no significant differences among the groups in the other measurements on the side-sagittal plane (Table. 4).

Ramus inclination and Occlusal plane to FH in cephalometric measurements were selected as variables significantly related to the VDS right ($P = 0.0003$) and Ramus inclination in cephalometric measurement was selected as a variable significantly related to the VDS left by stepwise regression analysis ($P = 0.0210$) (Table. 5).

In addition, all measurements of sphenoid sinus and pterygomaxillary region did not significantly related to age.
Post-operative complications

The procedures were shown in Table. 6. Le Fort I osteotomy with Intentional pterygoid plate fracture was performed in 36 of 47 class II female cases (72 of 94 sides) (Fig. 4) and sphenoid perforation was recognized in one side. However, there were no severe complications such as large amount blood loss or nerve injury (Fig. 4).

Discussion

Le Fort I osteotomy is a procedure frequently applied in orthognathic surgery to correct a wide range of malocclusion and maxillofacial deformities.

Complications in Le Fort I osteotomy can occur from dysjunction of the pterygoid plates from the posterior maxillary wall and the fissure is the triangular -shaped lateral opening of the pterygopalatine fossa formed by the divergence of the maxilla from pterygoid process of the sphenoid bone [29, 30]. The complications seemed to occur because of the close relation of the fissure to the pterygopalatine fossa, foramina of the base of the skull, and orbit [11, 13, 31–33]. The most common are intraoperative and postoperative hemorrhage secondary to damage to the maxillary artery and its terminal branches (descending palatine and sphenopalatine arteries), followed by varying degrees of maxillary ischaemic necrosis [35–37].

Furthermore, the anatomical structure of the sphenoid sinus is important when surgeons access to the pterygomaxillary region connected to the anterior region of the base of the skull. In-depth knowledge of this region has become essential to predict what may be found, so that possible anatomical variations can be accounted for, and iatrogenic lesions such as damage to the internal carotid artery and other important structures, can be avoided [38].

Sphenoid sinus traumas or inflammations can cause severe complications that are potentially fatal and visual changes that have been common ranging from 12–70% of isolated sphenoid diseases [39]. During the separation of the pterygomaxillary junction, due to the inappropriate forces to the base of the skull via the sphenoid bone and incorrect instrumentation, particularly when nasal septum osteotome is placed too high into the nasal cavity, sphenoid sinus and various adjacent vital structures may be damaged and serious bleeding, neurological complications or blindness, or even death may arise from the operation area [1, 4, 31]. Unwanted fractures extending the cranium could cause cavernous sinus thrombosis or carotid-cavernous sinus fistula; by this way, permanent cranial nerve damage could be observed [31, 32]. These neurological injuries could be isolated or combined and are related to direct or indirect injury [32]. Bony segments resulting from unexpected and unwanted fractures during down fracture of maxilla or with nasal septum or pterygoid osteotome may damage this region. On the other hand, various reasons such ischemia or contusion of a nutrient artery may cause indirect injuries of the adjacent cranial nerves.
It is described that direct trauma to the medial aspect of the cavernous sinus bypassing sphenoid sinus may cause neurological complications [40].

Moreover, east-Asian patients generally have a brachycephalic facial type, low projection of the nose, shorter anterior cranial base, and protrusive maxilla [16, 41–43]. Posterior repositioning of the maxilla is necessary for an optimum aesthetic profile in Asians, although the technique has several difficulties and complications. Ueki et al. first proposed the concept of the intentional pterygoid plate fracture with an ultrasonic bone curette [16]. After then some surgeons have reported the clinical evaluation including stability or healing pattern of the intentional pterygoid plate fracture with and without use of the ultrasonic bone curette [16–21]. The previous anatomical studies have showed that the distance from the internal maxillary artery to the inferior point of the pterygoid plate is approximately 23–28 mm [44, 45]. Based on the quantitative measurements of the fracture line, whether the fracture level was high or low, the most superior point of the fracture line was always far lower than the position of the internal maxillary artery [21]. However, in our experiences, the sphenoid sinus perforation occurred, although there was no internal maxillary injury and no symptom occur after surgery fortunately.

Furthermore, ethnicity, sex, and age are all factors that have an influence, and it has also been suggested that nasal airflow and positive air pressure in the nasopharynx affect the development of the paranasal sinuses and craniofacial growth [46]. According to some authors the development of the paranasal sinuses is linked directly to the growth of the facial part of the skull and with dentition [47, 48]. In the previous study without description regarding skeletal class, it was found that both maxillary and frontal sinus volumes were greater in males compared to females, but there was no statistically significant correlation between the volume of maxillary sinuses with age or side. It was reported that sex, facial type, and skeletal class had no significant influence on the volume of the sphenoid sinus, and nor did the volumes of the right and left sphenoid sinuses, or the presence of a septum within the sinus in its volume [49]. In this study, there was no correlation between sphenoid sinus and age and this finding was in accordance with the previous studies [46–49]. However, there were significant differences between class III male and class III female in HS, VDS and WS. Although there was significant difference between class II and class III in ML, this measurement showed antero-posterior length of maxillary sinus and might not reflect the sphenoid sinus.

The previous studies reported that the mean distance from the piriform fossa to the descending palatine canal was 38.4 mm in men and 34.6 mm in female [30], and 34.1 mm using CT of dry skull [50]. They stated that injury to the descending palatine artery during the Le Fort I osteotomy can be minimized by not extending the osteotomy more than 30 mm posterior to the piriform rim in females. In this study, the mean anterior length was 30.4 mm in class II female and 27.90 mm in class III female on right side, both shorter than other studies. This may be due to the difference in the measurement points, as we selected the distance between anterior wall and posterior wall of the maxillary sinus at the PNS level plane parallel to the FH plane on the side-sagittal plane involving the great palatine canal.
Furthermore, the differences in all measurements between the right and left sides did not correlate with asymmetric measurements, such as the Mx-Md midline. This suggested that the right-left difference in maxilla-mandibular asymmetry did not relate to the right left difference morphology of the sphenoid sinus and pterygomaxillary region.

This study was described to help the surgeons to access the sphenoid and the pterygomaxillary region when the Le Fort I osteotomy and removal of the bony interference with and without the intentional pterygoid fracture. Therefore, the anatomy of the anterior wall of sphenoid sinus and the posterior wall of maxillary sinus and great palatine canal was emphasized in the measurements. Especially, VDS represented the vertical distance from the PNS level to the sphenoid sinus wall. In short, after down fracture of maxilla, the knowledge of the distance was useful to perform the horizontal osteotomy at the frontal aspect of the pterygoid plate. The fracture level of the pterygoid plate can be determined referring the maxillary structure. In this study, the mean VDS was ranged from 18 to 20 mm, however the standard deviation of VDS was comparatively large (4–6 mm). The vertical distance to the sphenoid sinus is so varied that use of the pterygoid osteotome and the curved lateral nasal wall osteotome can damage the upper level of the pterygoid plate including sphenoid sinus, even if the intentional pterygoid plate fracture is not performed. When maxillary impaction at the posterior site and/or maxillary setback are performed, surgeon is forced to operate at the upper level of the pterygomaxillary region close to sphenoid sinus. The internal maxillary artery, descending palatine artery, sphenopalatine artery, superior palatine artery, the pterygoid venous plexus and the pterygoid muscles exist at the upper level of pterygopalatine fossa between the pterygoid plate including the sphenoid sinus and posterior wall of maxilla. From the results if stepwise regression analysis, Ramus inclination (right and left) and Occlusal plane to FH (Right) in cephalometric measurements were selected as variables related to the VDS. This suggested that the cephalometric analysis could be helpful to determine the horizontal fracture level of pterygoid plate. Although there was significant difference, the prediction using only the cephalometric measurements might not be accurate and realistic to determine the horizontal osteotomy at the frontal aspect of the pterygoid plate, clinically.

As a limitation of this study, the normal skeletal with normal occlusion control and class II male subjects were not prepared. Therefore, it was still unclear whether there were differences among all skeletal patterns including class II in male. Furthermore, larger sample number will be necessary to evaluate more objectively.

Anyway, surgeons must pay attention not only the bleeding from the vessels and the muscles but also the sphenoid bone damage including pterygoid plate and sphenoid sinus that sequentially can induce the fatal cerebral or nerve damage.

**Conclusion**

These results suggest that the sphenoid sinus exist more frequently recognized close to superior site of the pterygoid plate in class II female. However, the location of the sphenoid sinus at the pterygomaxillary
junction region could not be predicted accurately using cephalometric measurements analysis. CT examination is necessary to recognize the anatomy of sphenoid sinus and pterygomaxillary region before Le Fort I osteotomy with and without intentional pterygoid plate fracture.

**Declarations**

**Ethics approval and consent to participate**

This study was retrospective cohort This study was performed according to the Declaration of Helsinki and was approved by the Ethical committee of the University of Yamanashi. Receipt number 1125, November/20/2013. Informed consent was obtained for all participates.

**Consent for publication**

The authors affirm that human research participants provided informed consent for publication of the images in Figures 1-4.

**Competing Interests**

The authors have no relevant financial or non-financial interests to disclose.

**Author contributions (Ensure all authors are referred to in the statement)**

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by K Ueki, K Yoshizawa and A Moroi. All authors read and approved the final manuscript.

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**Availability of data and materials**

The data of this study were described in the Tables.

**References**


Tables
Tables 1 to 6 are available in the Supplementary Files section.

Figures

Figure 1

CT images. Measurements on the mid-sagittal plane involving ANS and PNS, A: mid-sagittal plane, B: coronal plane involving the midpoint between Sella and PNS parallel to FH plane, C: horizontal plane at the PNS level parallel to the FH plane.

1) HS: Height of sphenoid sinus on the SP line, on the mid-sagittal plane

2) APS: Antero-posterior length of sphenoid sinus parallel to FH, on the mid-sagittal plane

3) HDS: Horizontal distance between the SP line and PNS, on the mid-sagittal plane
4) VDS: Vertical distance between the sphenoid sinus wall on the SP line and PNS, on the mid-sagittal plane

5) SSm: Square of sphenoid sinus on the mid-sagittal plane

6) WS: Maximum width of sphenoid sinus on the coronal plane involving the SP line

7) SSc: Square of sphenoid sinus on the coronal plane involving the SP line

Figure 2

CT images. Measurements on the right side-sagittal plane involving the great palatine canal. A: the right side-sagittal plane, B: horizontal plane at the PNS level parallel to the FH plane.

1) HS right: Height of sphenoid sinus on the SP line, on the side-sagittal plane

2) APS right: Antero-posterior length of sphenoid sinus parallel to FH on the side-sagittal plane

3) HDS right: Horizontal distance between the SP line and the posterior wall of maxilla, on the side-sagittal plane

4) VDS right: Vertical distance between the sphenoid sinus wall on the SP line and PNS, on the side-sagittal plane

5) SS right: Square of sphenoid sinus on the side-sagittal plane
6) ML right: Distance between anterior wall and posterior wall of maxillary sinus at the PNS plane level (parallel to FH plane), on the side-sagittal plane

7) MSD right: Distance between anterior wall at the PNS plane level (parallel to FH plane) and sphenoid sinus wall, on the side-sagittal plane

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**Figure 3**

CT images. Measurements on the left side-sagittal plane involving the great palatine canal. A: the right side-sagittal plane, B: horizontal plane at the PNS level parallel to the FH plane.

1) HS left: Height of sphenoid sinus on the SP line, on the side-sagittal plane

2) APS left: Antero-posterior length of sphenoid sinus parallel to FH on the side-sagittal plane

3) HDS left: Horizontal distance between the SP line and the posterior wall of maxilla, on the side-sagittal plane

4) VDS left: Vertical distance between the sphenoid sinus wall on the SP line and PNS, on the side-sagittal plane

5) SS left: Square of sphenoid sinus on the side-sagittal plane
6) ML left: Distance between anterior wall and posterior wall of maxillary sinus at the PNS plane level (parallel to FH plane), on the side-sagittal plane

MSD left: Distance between anterior wall at the PNS plane level (parallel to FH plane) and sphenoid sinus wall, on the side-sagittal plan

![CT images. A: sphenoid sinus was intact after intentional pterygoid plate fracture. Arrows show the fracture sites. B: sphenoid sinus perforation and membrane hypertrophy or hematoma were found. Arrows show perforation of the anterior wall of the sphenoid sinus.](image)

**Figure 4**

CT images. A: sphenoid sinus was intact after intentional pterygoid plate fracture. Arrows show the fracture sites. B: sphenoid sinus perforation and membrane hypertrophy or hematoma were found. Arrows show perforation of the anterior wall of the sphenoid sinus.

**Supplementary Files**

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