

Clinical Paper
Orthognathic Surgery

Influence of the anatomical form of the posterior maxilla on the reliability of superior maxillary repositioning by Le Fort I osteotomy

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Abstract. Certain patients with facial deformities require superior repositioning of the maxilla via Le Fort I osteotomy; however, the magnitude of superior repositioning of the maxilla is often less than expected. In this study, the correlation between the accuracy of superior repositioning of the maxilla and the anatomical form of the maxillary posterior region was examined. Seventy-five patients who underwent Le Fort I osteotomy without forward movement of the maxilla but with superior repositioning of the maxilla were included in this study. The bone volume around the descending palatine artery (DPA), the angle of the junction between the pterygoid process and the tuberosity, and the distance between the upper second molar and the pterygoid process were measured via three-dimensional analysis. A significant negative correlation ($r = -0.566$) was found between the bone volume around the DPA and the ratio of repositioning (actual movement divided by expected movement). It is possible that the superior repositioning of the maxilla expected prior to surgery was not sufficiently attained because of the large volume of bone around the DPA. The results of this study show that in some patients, superior repositioning was not achieved at the expected level because of bone interference attributable to the anatomical form of the maxillary posterior region.

Key words: superior repositioning of the maxilla; Le Fort I osteotomy; anatomical form; descending palatine artery; pterygoid process; 3D analysis.

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The Le Fort I osteotomy is one of the primary methods used in orthognathic surgery, and it is applied in various situations¹. Superior repositioning of the maxilla is often required in the treatment of maxillofacial deformities with a vertical

maxillary excess, such as cases of long face, open bite, or mentum protrusion. Superior repositioning of the maxilla, i. e. total impaction and upward rotation of the posterior region of the maxilla, is technically challenging. Moving the maxillary bone to the planned position is difficult, often leading to a shortage of vertical movement of the posterior region of the maxilla, as verified by the position of the maxilla on lateral cephalograms after the operation. An inadequate posterior maxillary vertical reduction will result in intermaxillary fixation with the condyles outside the condylar fossa and either a post-surgical open bite or orthodontic extrusion of the anterior teeth.

The presence of the descending palatine artery (DPA) makes bone removal difficult, and it is believed that this difficulty results in insufficient superior repositioning of the maxilla in conventional Le Fort I osteotomy. Injury to the DPA in conventional Le Fort I osteotomy may cause severe bleeding due to the significant damage and tissue necrosis caused by the ligation of the DPA^{2,3}. Therefore, inadequate superior repositioning of the posterior portion of the maxilla could be due to insufficient bone removal around the DPA and a poor visual field due to bleeding from the pterygoid venous plexus. It is essential to evaluate the anatomical state of the bone around the DPA before the operation.

Many studies have examined the accuracy of the repositioning of the maxilla in Le Fort I osteotomy⁴⁻¹⁴, and some have included statistical studies on the anatomical position of the DPA¹⁵⁻¹⁸, but no study appears to have compared the anatomy of the posterior region of the maxilla and the accuracy of maxilla repositioning.

In addition, the dissection of the posterior region of the maxilla, particularly the pterygoid process of the sphenoid, will have an influence on results. In the case of superior repositioning of the maxilla without forward movement of the maxilla, bone interference always occurs in the posterior region. Several reports have documented movement to the planned position by breaking the pterygoid process of the sphenoid in cases where there is strong and substantial bone interference between the posterior region of the maxilla and the pterygoid process of the sphenoid¹⁹; however, this procedure is not always desirable because of the risk of bleeding. Fracture of the pterygoid plate also causes temporary hearing loss secondary to soft palate musculature detachment and serious bleeding; it is also time-consuming to address.

The purpose of this study was to determine the correlation between the accuracy

of the superior repositioning of the maxilla and the anatomical form of the maxillary bone, i. e., the bone volume around the DPA and the pterygoid process of the sphenoid, by three-dimensional (3D) analysis.

Patients and methods

This study included 75 patients (Japanese adults) with facial deformities who were treated in the Department of Maxillofacial Surgery at Tokyo Medical and Dental University Hospital between January 2008 and December 2017. The type of movement was described as superior repositioning when the movement was more than 4.0 mm at the posterior nasal spine (PNS) in the posterior region of the maxilla, without forward movement, in patients undergoing double jaw orthognathic surgery (Le Fort I osteotomy and bilateral sagittal split ramus osteotomy). Patients who underwent Le Fort I osteotomy with a horseshoe-shaped osteotomy and those with facial asymmetry were excluded. Among the 75 patients included, the maxillary posterior region with the maxillary upper incisor (U1) was maintained (the position of the incisor was not moved) in 51 patients, total impaction of the maxilla occurred in 18 patients, and maxillary superior repositioning around the anterior nasal spine (ANS) that had been moved was performed in six patients. Surgeons with more than 10 years of experience performing oral surgery operated on all of the patients.

The double jaw operation procedure involved a conventional Le Fort I osteotomy, which included removal of the bone around the DPA without a horseshoe-shaped osteotomy or a U-shaped osteotomy²⁰⁻²³. To move the posterior region of the maxilla upward, the bone around the DPA, the anterior wall of the maxillary sinus, and the side wall of the nasal cavity were removed. Guide holes were made at two points on the maxillary sinus anterior wall at the cuspid and first molar, above and below the osteotomy cutting line, as the vertical movement guide for the maxilla. The degree of vertical movement was determined by measuring the distance between the two points. In addition, the distance between the reference points and the base of the nose or internal canthus on the skin and the maxillary or mandibular orthognathic main lines were measured to determine the vertical position of the maxillary incisor. These reference points were measured, then the maxilla was guided to the planned position with a guide splint (intermediate wafer) and osteosynthesis was performed with four titanium miniplates with intermaxillary fixation²⁴.

The vertical ratio of superior repositioning of the maxilla was calculated as the

actual superior movement divided by the expected amount of movement. Measurement of the degree of maxillary movement was performed by tracing standard X-ray images (lateral cephalograms) obtained before the operation and within 1 month after the operation. The amount of actual superior repositioning of the posterior maxillary bone was measured at PNS. The *x*-axis (which served as the standard axis) was constructed by drawing a line through nasion 6° upward from the sella–nasion line, and the *y*-axis was drawn as a straight line crossing the *x*-axis and passing through the nasion point. The positions of the examined points were indicated on the *x,y*-axis²⁵. The X-ray images were traced three times to eliminate any technical measurement error, and the measurement value was reported as the mean of these values.

3D analysis software (Proplan CMF 3.0; Materialise, Leuven, Belgium) was used to examine computed tomography (CT) images (DICOM data) acquired before the operation. The vertical height of the maxilla (1–6 mm upward from the bottom of the nasal cavity) was set parallel to the Frankfort plane (Fig. 1A), and a circular region with a radius of 5.0 mm around the centre of the DPA was outlined on all of the 0.3-mm-interval slices (Fig. 1B). The centre of the circle, when set in the centre of the bone defect, was considered the DPA. By reconstructing all slices, a 3D structure of the bone around the DPA of 5.0 mm in height was extracted, and the volume of the structure was measured (Fig. 1C). The mean value of the measurements of the bone mass volume around the DPA obtained on the two sides (left and right) was recorded as the bone mass volume. Furthermore, the angle between the tangent line where the maxillary tuberosity joined the pterygoid process and the Frankfort plane was measured (Fig. 1D, angle 'a'), as well as the distance between the cervical point of the distal surface of the upper second molar and the point at which the maxillary tuberosity joined the pterygoid process (Fig. 1D, measurement 'b').

The precise position of U1 was traced and the shift in the position before and after the operation on a similar *x-y* axis was confirmed. The shift in the position from the planned position before the operation was measured in both the *x*-axis and *y*-axis directions as Δx and Δy , respectively. Furthermore, the angle of the shift in the palatal plane (i. e., the line connecting ANS and PNS) between the planned position and the postoperative position was also measured. The clockwise direction was assumed to be positive and the counterclockwise direction to be negative.

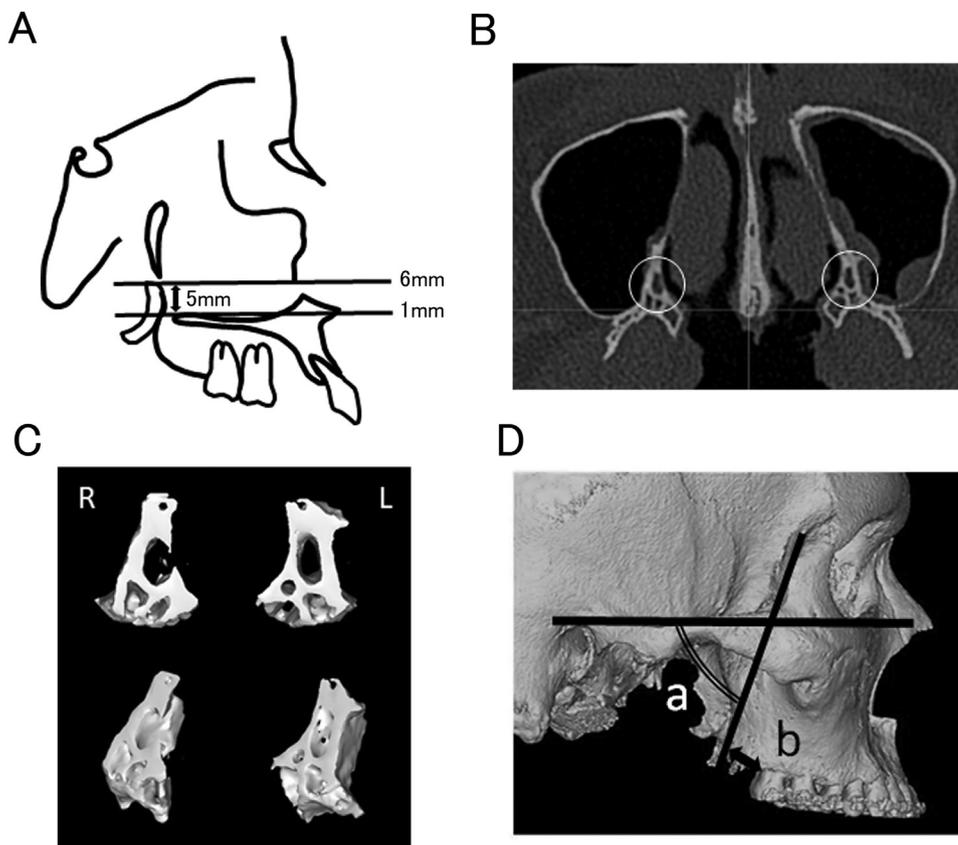


Fig. 1. (A) Setting of the vertical height of the maxilla was performed 1–6 mm upward from the bottom of the nasal cavity, parallel to the Frankfort plane. (B) The bone mass in a 5.0-mm radius from the centre of the descending palatine artery at each height was determined using 3D analysis software. (C) A 3D structure of the bone from around the descending palatine artery, of 5.0 mm in height, was obtained, and the volume of this structure was measured. (D) 3D image showing the angle between the tangent line where the maxillary tuberosity joins the pterygoid process and the Frankfort plane (angle 'a') and the distance between the cervical point of the distal surface of the upper second molar and the point at which the maxillary tuberosity joins the pterygoid process (measurement 'b').

For the statistical analysis, a two-group *t*-test and Pearson's product-moment correlation coefficient (correlations between the ratio of superior repositioning at PNS, Δx , and Δy and the bone mass volume around the DPA and palatal plain angle) were used. All data were recorded as the mean and standard deviation values, and differences were considered statistically significant at $P < 0.05$.

The study was performed in accordance with the Declaration of Helsinki and was approved by the Research Ethics Committee of Tokyo Medical and Dental University. Informed consent was obtained from all of the participants in accordance with the institutional guidelines.

Results

The mean ratio of superior repositioning at PNS (ratio of actual/planned movement of the vertical position of PNS) in this study was 0.79. There was a negative correlation between the ratio of superior repositioning

at PNS and the bone volume around the DPA ($r = -0.566$, $P = 0.01$; Fig. 2A). Using a cut-off level of 144 mm^3 , the group with bone volume values $>144 \text{ mm}^3$ had a significantly lower ratio of superior repositioning of the maxilla than the group with values of $<144 \text{ mm}^3$ ($P < 0.05$, Fig. 2B). However, there was no correlation between the ratio of superior repositioning and the angle of the junction between the pterygoid process and the maxillary tuberosity ($r = 0.260$, Fig. 2C). There was also no correlation between the ratio of superior repositioning of the maxilla and the distance between the second molar and the point at which the maxillary tuberosity joined the pterygoid process ($r = 0.250$, Fig. 2D).

There was a relatively weak tendency towards a forward positioning of U1 by Le Fort I osteotomy (the maxillary position before the operation was without maxillary forward movement) compared with the planned position (Fig. 3A). No correlation was observed between the bone

mass volume around the DPA and the horizontal and vertical shifts of U1 (Δx , Δy) (Fig. 3B). However, only a weak correlation between the displacement of U1 and the angle of the junction between the maxillary tuberosity and the pterygoid process was noted; it is thought that the bone interface at this location affected the precision of maxillary repositioning (Δx : $r = -0.179$, Δy : $r = -0.237$; Fig. 3C). The shifted position of U1 (Δx) tended to fix the direction of the former upper or lower position. As a result, because the maxillary incisor moved more towards the former upper direction than predicted, the ratio of superior repositioning at PNS was lower than expected.

There was also a difference between the planned position and the actual position of the palatal plane, and the inclination angle (pitch) of the palatal plane was positioned in the counterclockwise rotation compared with the planned position ($r = -0.273$, $P < 0.05$; Fig. 4). The result was regarded as a shift of U1 in a forward and downward

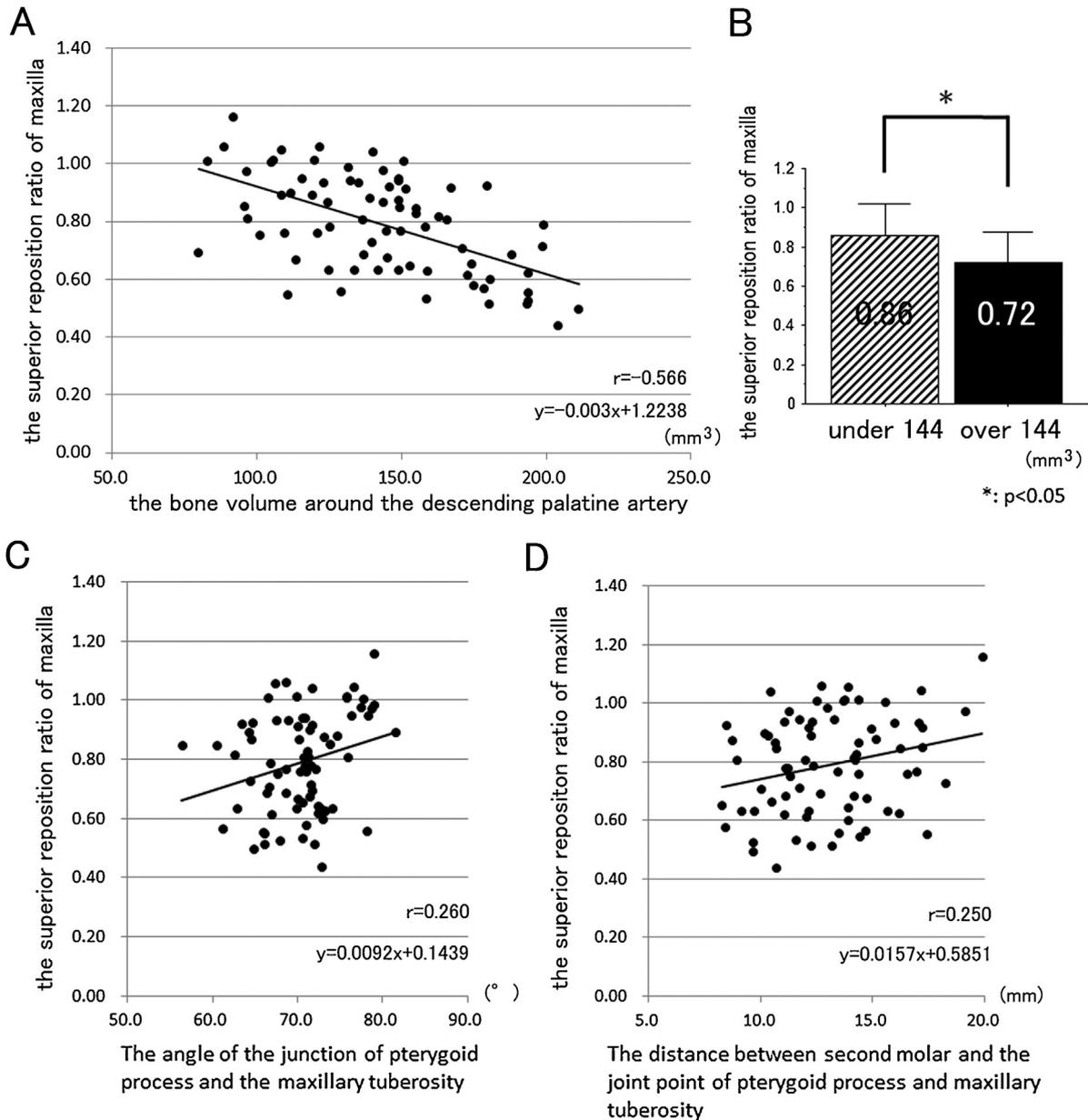


Fig. 2. (A) Correlation between the superior repositioning ratio at PNS and the bone volume around the descending palatine artery; a significant negative correlation was found. (B) The group with bone volume values >144 mm³ had significantly lower ratios of superior repositioning of the maxilla than the group with values of <144 mm³. (C) No significant correlation was found between the superior repositioning ratio of the maxilla and the angle of the junction between the pterygoid process and the maxillary tuberosity. (D) No significant correlation was found between the superior repositioning ratio of the maxilla and the distance between the second molar and the point at which the maxillary tuberosity and the pterygoid process join.

direction and a decrease in the superior repositioning of the maxilla.

Discussion

In this study of double jaw surgery cases involving more than 4.0 mm of superior movement at PNS of the maxilla, seen over a period of 10 years in the Department of Maxillofacial Surgery, Tokyo Medical and Dental University, the overall mean ratio of superior maxillary repositioning at PNS (actual movement divided by expected movement) was 0.79. There was a negative correlation between the ratio of superior maxillary repositioning and the bone volume around the DPA ($r = -0.566, P = 0.01$). It is possible that the superior repositioning of the maxilla expected prior to the operation was not sufficiently obtained because of the large bone volume around the DPA. In addition, it is suggested that the expected superior repositioning of the PNS may not be

achievable due to the bone interference between the maxillary tuberosity and the pterygoid process, as shown in this study. Furthermore, in the case that superior repositioning of the PNS was not modelled during planning, there was a tendency to fix the maxillary bone forward compared with the planned movement position of U1, and it is thought that the positioning accuracy of U1 greatly influenced the superior repositioning at PNS. According to a report by Iino et al.²⁶, during fixation

direction and a decrease in the superior repositioning of the maxilla.

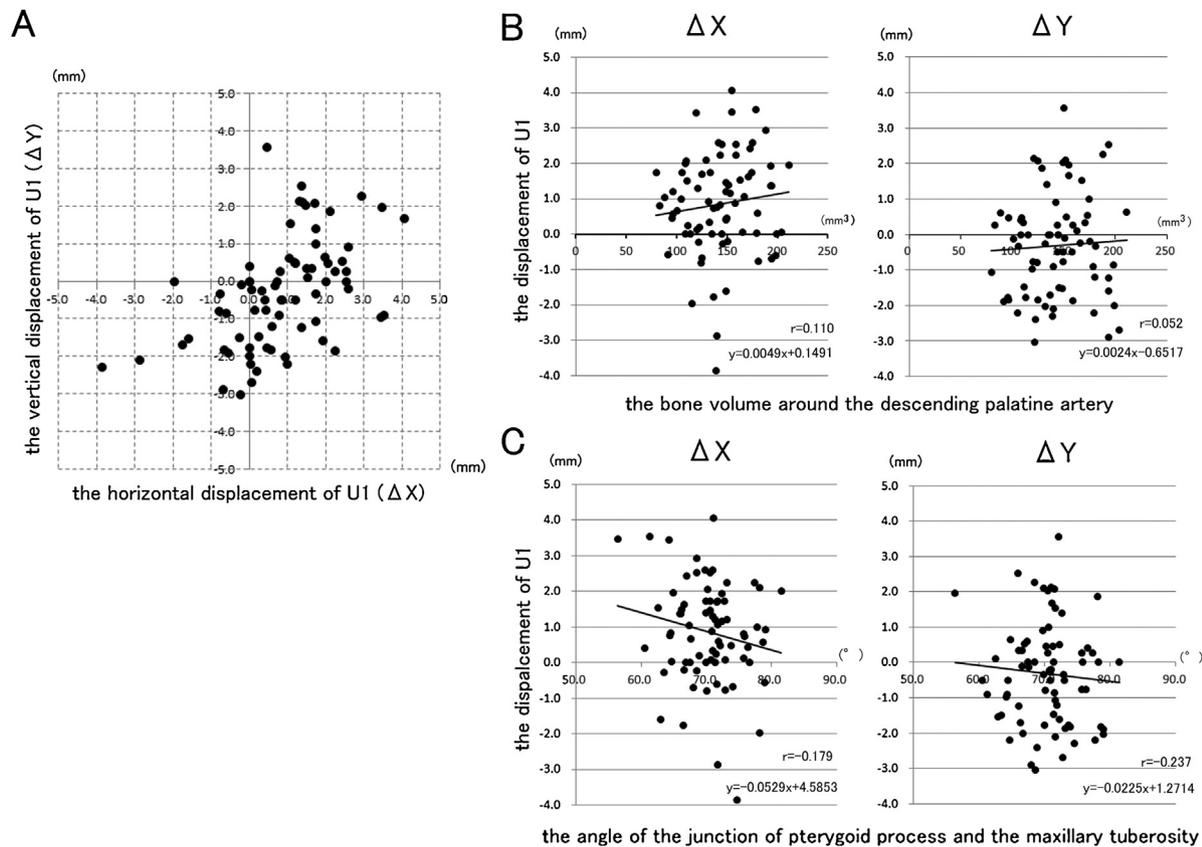


Fig. 3. (A) A relatively weak tendency towards forward positioning of U1 in Le Fort I osteotomy (without maxillary forward movement) was observed compared with the planned positioning. (B) No significant correlations were found between the bone volume around the descending palatine artery and the horizontal and vertical shift of U1 (Δx , Δy). (C) Weak correlations were identified between the angle of the junction between the pterygoid process and the maxillary tuberosity and the horizontal and vertical shift of U1 (Δx , Δy).

of the maxillary bone using the double splint method, the union of the maxilla and mandible by the intermediate wafer is rotated to the planned position at the mandibular head; however, it is believed that this method causes rotation when they are not in the original mandibular condyle position, therefore differing from the actual central turn in the modelled surgery, as has been reported by others^{10,27}.

In addition, the error in the maxillary posterior region caused more bone interference than was predicted before the operation, and the maxillary bone moved to the former lower part or the former upper part at a pivot point in the region of bone interference, as shown in Fig. 5. Shikimori et al. reported the stability and accuracy of the maxillary bone of four patients who underwent conventional Le Fort I osteotomy with superior repositioning of the maxilla²⁸. However, they did not achieve a sufficiently precise movement of the upper part of the posterior region of the maxilla and fixed the anterior region of the maxilla relatively forward or downward. As shown by the results of the present study, the interference of the bone around

the DPA and the bone interference between the maxillary tuberosity and the pterygoid process are fundamental issues. Removing the bone interference will increase the risk of damage to the vascular bundles and soft tissues, and could lead to an excessive operating time, bleeding, and hand stress, as well as diminished accuracy of positioning when performing superior repositioning of the maxilla. The results of this study showed that the deviation of U1 (Δx , Δy) tended to become large if the inclination of the junction with the pterygoid process was milder and if the bone volume around the DPA was large.

This study investigated the difference between the preoperative predicted movement and the position of the maxilla following the actual surgical procedures. In the study patients, the deviations from the planned movement were not sufficiently large to necessitate re-operation of the maxilla. To more accurately perform the operation described, it is extremely important to be aware of the patient's facial appearance and other preliminary assumptions prior to surgery, when one is explaining the procedure and obtaining consent

from the patient. The decision regarding whether to include 1–2 mm of forward movement of the maxilla will depend on the surgeon's skill and preferences; however, even if the surgeon believes that the surgery has proceeded as planned, the movement of the maxilla may not occur as planned, as described in this study. The accuracy of the movement was investigated postoperatively in this study. In cases in which the patient's facial profile has no deficiencies, given an appropriate preoperative setting, a forward movement of up to 2 mm may offset the risk of surgery. However, this possibility does not apply to Asian facial profiles²⁹, which involve a flatter face. For Asian patients, the morphology of the alar base is likely to be affected. Therefore, in certain cases, it is necessary to ensure that forward displacement of the settings does not exceed 2 mm. For patients who exhibit forward movement not accompanied by settings that account for the patient's profile and alar base, accurate movement of the maxilla is desirable.

Additionally, if preoperative CT assessment shows that superior repositioning of the posterior maxilla would be difficult

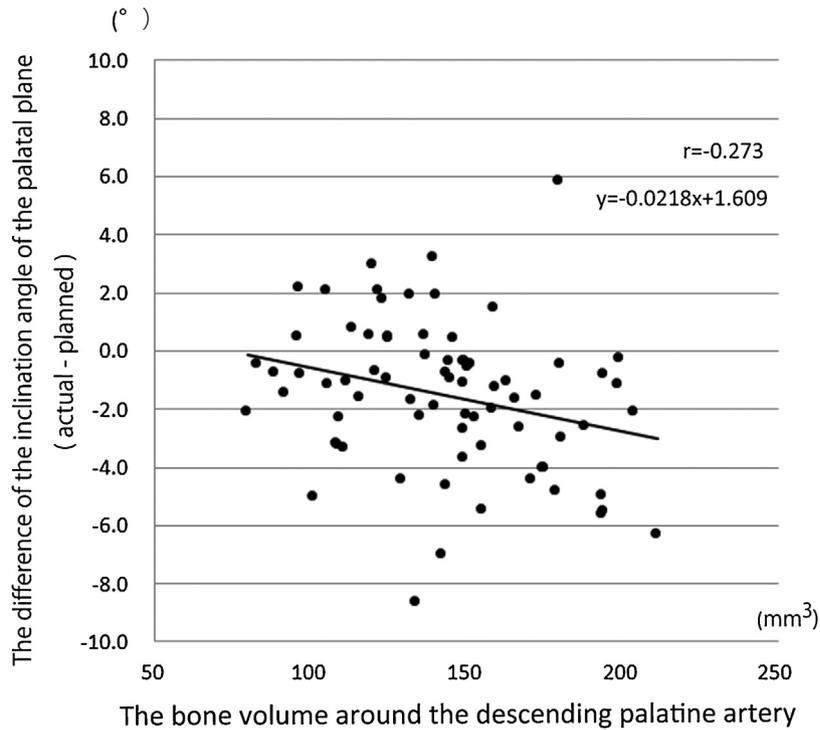


Fig. 4. The inclination angle (pitch) of the palatal plane was positioned in counterclockwise rotation compared with the planned position.

due to the bone morphology of the posterior maxilla and would compromise this forward movement of 2 mm, it becomes important to shorten the operation time and ensure a safe surgery that is free of complications.

Few studies have considered the correlation between the anatomy of the posterior region of the maxilla and Le Fort I osteotomy^{15-17,30}. Ueki et al. investigated the location of the DPA and the morphology of the pterygoid process horizontally¹⁵. Kawahara et al. showed that the average lateral distance, i.e. the length of bony contact between the posterior maxilla and the pterygoid plate that should be separated by an osteotome, was 8.09 mm (range 3.75–13.59 mm)¹⁷. A long bony contact increases the difficulty of the pterygomaxillary disjunction and the risk of an untoward fracture leading

to arterial injury. In the study by Kanazawa et al. concerning the risk of pterygoid plate fracture, the authors reported a pterygomaxillary junction thickness of 2.6 ± 1.7 mm and a maxillary tuberosity length of 11.5 ± 3.8 mm³⁰. A pterygomaxillary junction thickness of <2.6 mm and a maxillary tuberosity length of >11.5 mm were associated with a statistically significant risk of pterygoid process fracture. How the separation at the pterygomaxillary junction affects superior repositioning of the maxilla is unclear. However, experienced surgeons may be able to remove bone from the bone interference area such that the distance is sufficiently large to avoid damage to the teeth. The difficulty of bone removal in superior repositioning changes how the pterygoid junction and the bone around the DPA are divided in the down-fracture

of the maxillary bone. Ueki et al. reported that 40.6% of all cases could be divided at the pterygoid junction¹³. As reported in several papers^{31,32}, it is also important to set the osteotomy at the lower portion of the posterior maxilla and to perform the osteotomy at the maxillary nodule to avoid the pterygoid plate in cases involving a long distance between the second molar and the joint of the maxillary tuberosity and pterygoid process. In the present study, how the actual division was performed was not evaluated; however, an increased bone length of the maxillary tuberosity led to greater reliability in superior repositioning of the maxilla.

The results of the present study indicate that the precision of the position of U1 is greatly influenced by the accuracy of superior repositioning. To determine the position of U1, reference guide holes were

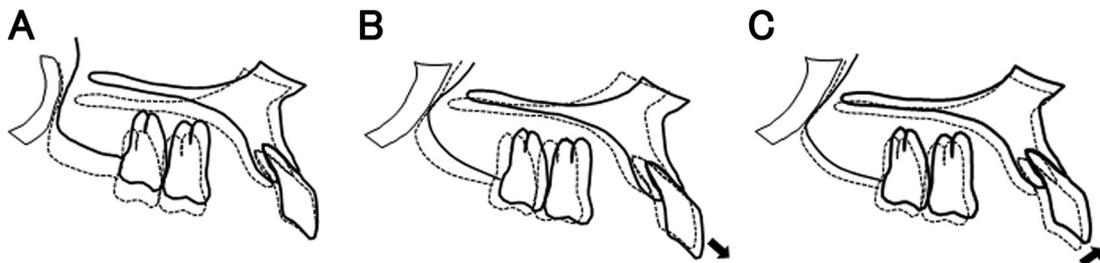


Fig. 5. The error in positioning of the maxillary posterior region caused more bone interference than was predicted before the operation (A), and the maxillary bone moved to the former lower part (B) or the former upper part (C) at a pivot point in the region of bone interference.

set in the bone above and below the maxillary bone cutting line in the oral cavity (internal reference points) and in the facial area, such as the nasal bone region or the former facial skin (external reference points). The external reference points were assessed in the following two ways: on the skin and in the bone using screws. Several reports have shown the usefulness of the bone reference, but a skin reference was also used in the present study, which left a scar on the face^{7,33}. Gil et al. reported that a method using the medial canthal region as an external reference point was also effective³⁴. However, a proper position could not always be determined because of the influence of the intubation tube, muscle relaxation, positioning of the mandibular head, and accurate measurement of reference points.

With the double splint method, it is important that the positional relationship between the skull and the maxilla–mandibular complex via intermediate wafer must be consistent with that before the osteotomy. As shown in this study, measuring the distances between the conventional reference points is inferior in reliability. Three-dimensional methods using straight rocking miniplates and resin tubes have been reported and are considered reliable without requiring complicated distance measurements^{35,36}. Meanwhile, positioning the maxilla may be difficult and the operative time may be prolonged due to bleeding and bone interference. The present authors often use an additional osteotomy to effectively remove strong bone interference in order to avoid bone removal around the DPA – either a horseshoe-shaped osteotomy^{21,22}, or a U-shaped osteotomy²³, along with Le Fort I osteotomy. Furthermore, we attempt to fracture the pterygoid process and push it backwards. The distance between the molar tooth root apex and the base of the nasal cavity, as well as the shape of the pterygoid process before the operation, must be verified.

Some reports suggest a method to adequately remove bone interference by ligating the DPA during planned superior repositioning of the posterior maxilla^{37,38}. Routine ligation of the DPA during Le Fort I osteotomy is controversial from the perspective of the blood supply to the maxilla. Bays et al. reported a low incidence of aseptic necrosis (0.67%) after routine bilateral ligation of the DPA³⁹. Lanigan et al. stated that the DPA should be preserved whenever possible to minimize the risks of postoperative haemorrhage and aseptic necrosis⁴⁰. In cases involving post-surgical bleeding after Le

Fort I osteotomy, although haemostasis has reportedly been achieved via either ligation of the external carotid artery or radiologically assisted arterial embolization of the posterior maxilla^{41,42}, preservation of the DPA should not significantly increase the risk of postoperative haemorrhage⁴³. Therefore, in the surgical procedures that we perform, the DPA is preserved whenever possible to maintain the blood supply to the maxilla after Le Fort I osteotomy.

Based on this information, the accuracy of maxillary front tooth region positioning must be ensured after noting not only the bone interference of the upper region around the DPA, but also the bone interference between the pterygoid process and the maxillary tuberosity of the posterior region during superior repositioning of the maxilla. To increase the accuracy of a determined, effective reference point in maxillary repositioning, it is necessary to create the correct wafer and apply the position-affiliated record between the skull and the proximal mandibular ramus spicule. Recently, simulation software, navigation^{44,45}, 3D-printed models, and CAD/CAM-generated splints⁴⁶ have been introduced to the field of orthodontic surgery, making it possible to create more precise wafers. These programs are expected to have more practical use in the future. Regardless, preoperative plans must consider the type of movement most suitable to the anatomical form of the posterior region of the maxilla when performing superior repositioning of the posterior upper jaw.

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None.

Competing interests

None declared.

Ethical approval

The Research Ethics Committee of Tokyo Medical and Dental University (approval number D2014-18).

Patient consent

Not required.

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