Measurement of the Maxilla and Zygoma as an Aid in Installing Zygomatic Implants

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Purpose: This study used maxillary and zygomatic measurements to obtain information for installing zygomatic implants.

Patients and Methods: Angular and linear distances between the maxilla and the zygoma were measured in 12 cadavers (n = 22 sides) classified into short and tall groups by height (140 to 159 cm and 160 to 180 cm, respectively).

Results: Based on mean and standard deviation values, the installation angle of zygomatic implants was between 43.8° and 50.6°. The distance between the crest of the maxillary alveolar process near the palate and the jugale (Ju) point of the zygoma was between 44.3 and 54.3 mm. The minimum distance between the most lateral corner of the maxillary sinus and the Ju point was 6.41 mm, and the minimum anteroposterior length of the zygoma was 5.68 mm in the shorter group.

Conclusions: When the installation angle of zygomatic implants is 43.8° or less, perforation of the maxilla and the zygoma or the infratemporal fossa must be avoided. When the angle is 50.6° or more, perforation of the orbital floor must be avoided. Special attention is needed to ensure osseointegration in shorter patients, because the distance between the most lateral corner of the antrum supporting the zygomatic implant and the Ju point is 10 mm or less. The apex of the implant is 3.75 mm in diameter, and the thickness of the zygoma must be 5.75 mm or more. The threads of the implant must not be exposed from the zygoma in shorter patients.

Bone grafting is performed to place endosseous implants in patients with maxillary defects resulting from tumor resection or in patients with severe bone resorption of the maxillary alveolar process. However, oral and maxillofacial surgeons may face serious problems in managing patients if the bone graft is rejected or the procedure fails. The zygomatic implant (Nobel Biocare AB, Göteborg, Sweden), which is expected to eliminate or minimize the need for bone grafting, has recently been developed.1,2 Zygomatic implants are inserted from the crest of the alveolar process (at a position in the second premolar region of the maxillary alveolar process and in a slightly palatal position), along the lateral wall of the maxillary sinus into the zygoma. In such cases, stable retention of the prosthesis can be achieved by placing 2 or more implants (standard type) in the anterior maxilla in addition to 1 or 2 zygomatic implants.2,5

It is important for oral and maxillofacial surgeons to clearly understand the detailed anatomy of the maxilla and the zygoma before undertaking surgery for the installation of zygomatic implants.2 However, there have been no fully satisfactory anatomic studies of the maxilla and the zygoma for the installation of zygomatic implants. The purpose of this study was to obtain anatomic information to ensure the safe installation of zygomatic implants by measuring angular and linear distances of the maxilla and the zygoma in cadavers.

Patients and Methods

Patients

Twelve cadaver heads (22 hemimaxillae and hemizygomata) from the collection of the Department of
Anatomy of Saga Medical School were used. The body heights of the cadavers ranged from 140 to 180 cm (159 ± 14.2 cm), with the height unavailable for 2 cadavers (4 sides). The cadavers were divided into 2 groups based on the height distribution of samples: a shorter group (n = 11) (140 to 159 cm height) and a taller group (n = 7) (160 to 180 cm body height). Of the 22 sides, molars were present on 10 sides. In these 10 sides, the positional relationship between the infraorbital foramen and the maxillary teeth was evaluated. Criteria for exclusion from the study included specimens from cadavers whose medical records showed diseases involving the zygoma, maxilla, or maxillary sinus; specimens from cadavers showing marked facial asymmetry; and specimens from cadavers in which thickening of the antral membrane was found when the maxillary sinus was exposed. In each specimen, the region from the orbit to the maxilla was detached from the head and the nasal bone, the maxilla, and the zygoma were exposed.

LANDMARKS

The midsagittal (Md) plane was defined as the plane passing through 3 points: 1) the midpoint of the superior margin of the nasal bone (nasion) (N), 2) the deepest point shifted from the inferior anterior margin of the anterior nasal spine toward the anterior surface on the alveolar process of the maxilla (subspinale) (Ss), and 3) the incisive foramen. The plane through the bilateral infraorbital foramina (IF) perpendicular to the Md plane is also defined as PTBIF. Point A is defined as the point corresponding to the starting point for the insertion of the zygomatic implant, which is shifted 5 mm toward the palate from the most inferior point of the alveolar process that crosses the line passing through the infraorbital foramen parallel to the Md plane. The jugale (Ju), corresponding to the endpoint reached by the implant, is defined as the point on the zygomatic lateral surface at the most depressed point of the transitional region from the lateral margin of the zygomaticofrontal process to the upper margin of the zygomaticotemporal process. Point B is a point located at the most lateral corner of the posterosuperior roof of the maxillary sinus. An angle (the angle between the PTBIF and the AJu) and linear distances (AJu and BJu) were measured.
It is also essential to determine the mean anteroposterior length of the maxillary zygomatic process and zygoma to avoid exposure of the threads on the anteroposterior side after installation of the zygomatic implant. Thus, points C to H were defined for measurement of the anteroposterior length of the maxillary zygomatic process and zygoma (Fig 2). Point C is the point where the line passing through the corner of the inferior crest of the zygomatic process (CICZP), parallel to the Md plane, crosses the PTBIF, and is defined as a point on the anterior surface of the maxillary zygomatic process. Point D is defined as the point on the posterior surface of the zygomatic process corresponding to point C where the maxillary anteroposterior length is minimum. Point E is the point where the line passing through the most inferior point of the maxillary zygomatic suture (Zm) parallel to the Md plane crosses the PTBIF, which is defined as a point on the zygomatic lateral face. Point F is defined as the point on the zygomaticotemporal face corresponding to point E where the zygomatic anteroposterior length is minimum. Point G is the point where the line parallel to the Md plane, passing through the Ju point crosses the PTBIF, and is defined as a point on the zygomatic lateral face. Point H is the point on the zygomaticotemporal face corresponding to point G where the zygomatic anteroposterior length is minimum. Anteroposterior lengths (C to D, E to F, and G to H) were measured.

FIGURE 2. Landmarks and measurements for the anteroposterior lengths on the maxilla and zygoma, which are defined as aids in installing zygomatic implants (frontal and axial views). Point C is the point where the line passing through the corner of the inferior crest of the zygomatic process [CICZP] parallel to the Md plane crosses the PTBIF and is defined as a point on the anterior surface of the maxillary zygomatic process. Point D is defined as the point on the posterior surface of the zygomatic process corresponding to point C where the maxillary anteroposterior length is minimum. Point E is the point where the line passing through the most inferior point of the maxillary zygomatic suture (Zm) parallel to the Md plane crosses the PTBIF, which is defined as a point on the zygomatic lateral face. Point F is defined as the point on the zygomaticotemporal face corresponding to point E where the zygomatic anteroposterior length is minimum. Point G is the point where the line parallel to the Md plane passing through the Ju crosses the PTBIF and is defined as a point on the zygomatic lateral face. Point H is the point on the zygomaticotemporal face corresponding to point G where the zygomatic anteroposterior length is minimum. Anteroposterior lengths (C to D, E to F, and G to H) were measured.

ANGULAR AND LINEAR MEASUREMENTS

Based on the points previously defined, an angle and 5 linear distances were measured (Figs 1, 2). To determine the installation angle (i.e., the angle between the PTBIF and the A-Ju), a protractor was used for measurement. The distance between the crest of the maxillary alveolar process near the palate and the zygoma (A-Ju) was measured using calipers (Mitsutoyo, Kanagawa, Japan). The distance between the most lateral corner of the maxillary sinuses and the Ju (B-Ju) and the maxillary zygomatic process and zygomatic anteroposterior lengths (C to D, E to F, and G to H) were measured using an external dial caliper gauge (Mitsutoyo, Kanagawa, Japan). All measurements were performed by the same researcher to minimize error.

MEASUREMENT ERRORS

The reproducibility of the measurements obtained was evaluated by randomly selecting a specimen used in the study, measuring an angle and 5 linear distances using the methods previously described, and obtaining these measurements again 1 week later. The measurement errors obtained, which were calculated as the difference between corresponding measurements, were expressed in terms of s(i) values as follows:

\[ s(i) = \sqrt{\frac{\sum (X_{ui} - X_{xi})^2}{N}} \]

STATISTICAL ANALYSIS

In the statistical analysis, Excel 2000 (Microsoft Co, Redmond, WA) was used, and the mean and standard deviation of each measurement were obtained for all specimens and height groups. In addition, the Student's t-test was used to identify measurement differ-
ences between the 2 height groups. For measurements in which significant differences ($P < .05$) were observed between height groups, the Pearson correlation coefficient between the height and measurement value was obtained.

**Results**

**POSITIONAL RELATIONSHIPS BETWEEN THE INFRAORBITAL FORAMEN AND THE MAXILLARY TEETH**

For dentate maxillae with molars (10 sides), a line parallel to the Md plane and passing through the infraorbital foramen crossed the second premolar of the maxilla on 9 sides. In the remaining specimen, the line crossed the proximal surface between the maxillary second premolar and the first molar.

**RELIABILITY OF MEASUREMENTS**

Measurement error was $0.20^\circ$ or less for the angle and $0.15$ mm or less for linear distances.

**ANGLE AND LINEAR MEASUREMENTS OF THE MAXILLA AND THE ZYGOMA**

The mean values and standard deviations for all specimens and height groups, respectively, are shown in Table 1.

**INSTALLATION ANGLE**

The range of installation angles defined as the angle between the PTBIF and the A-Ju, which was the sum of the mean and standard deviation values, was between $43.8^\circ$ and $50.6^\circ$. The maximum value was found in the shorter group, and the minimum value was found in the taller group. Significant differences were recognized between the height groups ($P < .005$). The correlation coefficient between height and the installation angle was $\gamma = -0.76$.


The range of the distance between the crest of the maxillary alveolar process near the palate and the zygoma (A-Ju), which was the sum of the mean and standard deviation values, was between 44.3 and 54.3 mm. The minimum length was found in the shorter group, and the maximum length was found in all specimens. No significant differences were recognized between height groups ($P > .05$).

**DISTANCE BETWEEN THE MOST LATERAL CORNER OF THE MAXILLARY SINUS AND THE JU (B-Ju)**

The mean distance between the most lateral corner of the maxillary sinus and the Ju (B-Ju) was 10 mm or less only in the shorter group. The minimum value, which added the mean and standard deviation, was 6.41 mm in the shorter group. Significant differences were recognized between height groups ($P < .0005$). The correlation coefficient between height and the B-Ju line was $\gamma = 0.81$.

**MAXILLARY ZYGOMATIC PROCESS AND ZYGOMATIC ANTEROPOSTERIOR LENGTHS (C TO D, E TO F, AND G TO H)**

The mean value of G-H was the smallest of the 3 measurements in each group. The G-H line, which was the sum of the mean and standard deviation values, was smallest in the shorter group at 5.68 mm. No significant differences were recognized between height groups ($P > .05$).

**Discussion**

In this study, the Frankfort plane could not be used as a standard plane, because only the region from the orbit to the maxilla was detached from the head of the cadaver. Therefore, the Md plane and the PTBIF, which can be determined in either edentulous or dentate jaws and are not affected by severe resorption of the alveolar process, were used as standard planes in this study. Under such conditions, measurement error in the angular and linear distances of the maxilla and the zygoma was 10% or less in terms of standard deviation for all specimens ($n = 22$) (Table 1). Therefore, the measurement method used in this study is considered precise and reliable.

| Table 1. ANGLE AND LINEAR DISTANCES OF THE MAXILLA AND ZYGOMA |
|---------------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| Group                          | Installation Angle ($^\circ$) Mean ± SD | A-Ju (mm) Mean ± SD | B-Ju (mm) Mean ± SD | C-D (mm) Mean ± SD | E-F (mm) Mean ± SD | G-H (mm) Mean ± SD |
| All ($n = 22$)                 | 47.5 ± 2.32        | 50.2 ± 4.13        | 12.2 ± 5.53        | 11.6 ± 1.78        | 9.67 ± 1.77        | 7.79 ± 1.59        |
| Height                         |                    |                    |                    |                    |                    |                    |
| 140 to 159 cm ($n = 11$)       | 49.3 ± 1.27*       | 49.0 ± 4.72        | 8.94 ± 2.53†       | 11.9 ± 1.70        | 9.92 ± 2.17        | 7.87 ± 2.19        |
| 160 to 180 cm ($n = 7$)        | 45.7 ± 1.89*       | 49.9 ± 1.44        | 18.8 ± 4.41†       | 10.8 ± 1.77        | 9.23 ± 1.56        | 7.64 ± 0.74        |

* $P < .005$.
† $P < .0005$.
The starting point for the installation of a zygomatic implant is the position in the second premolar region of the maxillary alveolar process and in a slightly palatal position.\textsuperscript{2,3} However, when zygomatic implant installation is planned, patients are frequently edentulous or lack molars. The position of the second premolar can be estimated from the infraorbital foramen based on the results of anatomic studies.\textsuperscript{4,5} In almost all specimens with dentate maxillae (9 sides) examined in our study, the plane parallel to the Md plane passing through the infraorbital foramen crossed the maxillary second premolar. The infraorbital foramen can easily be identified by exposing the lateral surface of the maxilla by an incision in the oral vestibule. Accordingly, the infraorbital foramen is a useful anatomic landmark for the installation of zygomatic implants.

After the starting point for the installation of a zygomatic implant is determined based on the infraorbital foramen, the installation angle of the implant through the maxillary sinus into the zygoma must be carefully determined. This will avoid damage to important anatomic structures, nerves, and blood vessels in the orbit and infratemporal fossa after perforation of the maxilla and zygoma. Furthermore, the installation angle is determined preoperatively to prevent interference with the osseointegration process because of contact between soft tissues and the zygoma. The zygomatic implant developmental team,\textsuperscript{1} which has been working with Brånemark,\textsuperscript{2} reported that the key to successful placement of a zygomatic implant is to determine the correct angle for installation of the implant. In short, determination of the installation angle is the most important factor in the procedure. The installation angle measured in our study ranged from 43.8° to 50.6°, taking into consideration the mean and standard deviation for individual differences among the measured values. Therefore, perforation into the lateral side of the maxilla and the zygoma, or the infratemporal fossa, is possible if the installation angle is 43.8° or less with the PTBIF defined as a standard plane, and penetration into the orbital floor is possible when the installation angle is 50.6° or more. Furthermore, a comparison of the installation angle between the height groups showed a statistically significant difference, with a strongly negative correlation between the installation angle and height ($\gamma = -0.76$). Accordingly, the optimal installation angle is presumably dependent on the patient’s height: the greater the height, the smaller the angle; the shorter the height, the larger the angle.

Once the installation angle has been determined, the distance between the starting point of installation and the apex of the zygomatic implant reaching the outer cortical layer of the zygoma is determined. It is useful to take into consideration the mean and standard deviation for individual differences in this distance preoperatively when determining the length of the zygomatic implant, which should ensure a smoother surgical procedure. The minimum value (A-Ju line), based on the mean and standard deviation values, was 44.3 mm in the shorter group. The minimum value was 46 mm or more in all specimens, as well as in the taller group. Zygomatic implants are available in lengths from 30 to 50 mm in 5-mm steps.\textsuperscript{2,5} Accordingly, a 40-mm zygomatic implant may be appropriate for patients who are less than 159 cm in height. In patients who are 160 cm or more in height, a longer zygomatic implant of 45 or 50 mm is more appropriate.

A zygomatic implant is supported by osseointegration in both the maxillary alveolus and the zygoma. In particular, the zygoma is in close proximity to the defect in the maxillary alveolar bone, which has satisfactory bone quality. Consequently, the distance between the most lateral corner of the maxillary sinus and the outer cortical layer of the zygoma engaged by the zygomatic implant is essential information for ensuring proper osseointegration. The mean distance between the most lateral corner of the maxillary sinus and the Ju point measured in this study was 10 mm or less only in the shorter group. In addition, the minimum was 6.41 mm in the shorter group, taking into consideration the mean and standard deviation for individual differences among the measured values. The results of a previous study\textsuperscript{6} revealed that the long-term clinical outcome is not favorable when a standard Brånemark implant 3.75 mm in diameter and 10 mm or less in length is installed in the posterior maxilla. Therefore, special attention must be given to achieve good osseointegration of the zygomatic implant, because the distance between the most lateral corner of the maxillary sinus and the Ju point is likely to be 10 mm or less in patients less than 159 cm in height. Moreover, the distance between the most lateral corner of the maxillary sinus and the Ju point showed statistically significant differences between the height groups, and a strongly positive correlation with height was observed ($\gamma = 0.81$). Consequently, the distance between the lateral corner of the maxillary sinus and the Ju point is probably dependent on the patient’s height: the greater the height, the longer the distance, the shorter the height, the shorter the distance.

It is essential to determine the mean anteroposterior length of the maxillary zygomatic process and zygoma preoperatively to avoid exposure of the threads after installation of the zygomatic implant. The mean anteroposterior length at 3 points from the maxillary zygomatic process to the zygoma through which the zygomatic implant passes laterally was gradually decreased in this study, and the G-H was the
shortest. Taking into consideration the mean and standard deviation for individual differences among the measured values, the minimum G-H was 5.68 mm in the shorter group. Triplett et al reported that the apical portion of a zygomatic implant installed in the zygoma is 3.75 mm in diameter. Frodel et al reported that the bone surrounding an osseointegrated implant should be at least 1-mm thick. In other words, the thickness of the zygoma around the apical portion of the implant should be at least 5.75 mm. Therefore, oral and maxillofacial surgeons should be very careful to avoid exposure of the threads of the implant from the zygoma when zygomatic implants are installed in patients less than 159 cm in height.

With regard to the selection of candidates for zygomatic implants, Reichert et al investigated this point by installing 18 implants in 12 patients and recommended the use of zygomatic implants as supports for prostheses in patients with maxillary defects resulting from tumor resection, severe resorption of the posterior maxilla, or unsuccessful autogenous bone grafts, as well as in patients who refuse autogenous bone grafting, according to the indications of the zygomatic implant developmental team. We agree with these guidelines for the selection of patients for zygomatic implants and recommend that the zygomatic implant procedures be performed based on the measurements obtained in the present study.

References