Computed tomography and anatomical measurements of critical sites for endosseous implants in the pterygomaxillary region: a cadaveric study


Abstract. The aim of this study was to obtain computed tomography (CT) and physical measurements of the pterygomaxillary region to determine the anatomical and radiographic landmarks that clinicians need for pterygoid implant placement. Seventy-eight hemi-heads with an atrophic posterior maxilla from 46 cadaveric samples were measured using CT. Twenty-one hemi-heads were selected randomly for physical measurements. CT measurements showed that the mean and minimum distance between the maxillary tuberosity point (MT) and the most lateral lowest point of the pterygomaxillary fissure (PF) were 18.7 mm and 10.0 mm, respectively. The mean and minimum distance between the alveolar crest point passing the extended line of the infrazygomatic crest and the PF were 22.7 mm and 14.7 mm, respectively. The mean and minimum distance between the PF and the greater palatine canal were 2.9 mm and 0.2 mm, respectively. Physical measurements showed that the mean and minimum distances between the MT and the descending palatine artery (DPA) were 19.4 mm and 12.7 mm, respectively, and those between the PF and the DPA were 3.7 mm and 0.0 mm, respectively. The results confirmed considerable variation in the values of the pterygomaxillary region measured at the specific sites. Therefore, careful and sufficient consideration is required in each case of pterygoid implant placement.

In the late 1980s, Tulasne introduced the tilted endosseous implant placement procedure from the maxillary tuberosity into the pterygoid process of the sphenoid bone for the treatment of the atrophic edentulous posterior maxilla. Although this procedure has been applied widely since its introduction, it is also challenging. Both Graves and Venturelli suggested that the implant be directed 45° to the occlusal plane. In 1998, in an anatomical study, Yamamura et al. used a cadaveric maxilla to measure the angles of inclination of possible pillars of bone between the maxillary tuberosity and the pterygoid.
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process. In 2001, Lee et al. measured the pyramidal process of the palatine bone that is related to pterygoid implants in dry skulls.

On the other hand, Rodriguez et al. used clinical data and panoramic radiographic images of pterygoid implants to report that a mesiodistal inclination of a pterygoid implant at 70° to the Frankfort horizontal (FH) plane decreases the non-axial loads of rehabilitation and exhibits good long-term survival. In 2014, Rodriguez et al. used cone beam computed tomography (CBCT) data of 100 cases and placed a virtual pterygoid implant in these; they reported that the mesiodistal inclination relative to the FH plane was 72.5 ± 4.9° and the distance between the maxillary tuberosity and the extremity of the pterygoid process was 22.15 ± 1.56 mm. These studies by Rodriguez et al. provided information from indirect measurements using panoramic radiography and CBCT, while the previous cadaveric studies did not focus on vessel information.

This study aimed to obtain measurements for the branch sites of the maxillary artery using both CT data and cadaveric samples, to identify effective landmarks that clinicians require for pterygoid implant placement.

Materials and methods

Materials

Forty-six Japanese cadavers were obtained from the Department of Anatomy of Saga Medical School and were examined with the approval of the Ethics Committee of Saga Medical School. An atrophic posterior maxilla with all molars missing was chosen for the study (i.e., CT measurement showing ≤10 mm between the alveolar crest and the sinus floor in the molar region), as described by Rodriguez et al. Thus, 78 hemi-heads were selected (42 hemi-heads from 24 males and 36 hemi-heads from 22 females). The age range at time of death was 65–100 years (mean 81 ± 9.1 years). All the cadavers had been fixed in a 10% neutral formalin solution. Thirteen of the 46 cadavers (21 hemi-heads) were selected randomly for physical measurements. The head was detached from the neck in all cases.

Methods

CT measurements

A multi-slice CT system (SOMATOM Emotion 16-slice configuration; Siemens, Germany) was used for CT measurements. The imaging parameters were the following: tube potential 130 kV, tube current 150 mA, scan time 1 s, gantry tilt 0, slice

Fig. 1. Images of the area between the inferior orbital margin and the maxillary alveolar process: (A) three-dimensional, (B) sagittal, and (C) axial views at the zygomatic arch level. The yellow arrow shows the lowest posterior point of the maxillary tuberosity ‘MT’; the red arrow indicates the most lateral lowest point of the pterygomaxillary fissure ‘PF’; the green arrow shows the central lowest point where the alveolar crest passes through the extended line of the infrayzygomatic crest ‘A’; and the white arrow shows the greater palatine canal ‘GPC’. The white horizontal line including point A in Fig. 1B indicates the plane parallel to the Frankfort horizontal (FH) plane. The white double-headed arrow (Fig. 1B) indicates the residual alveolar bone height, i.e. the linear distance from point A to the maxillary sinus floor on the line perpendicular to the FH plane including point A.
thickness 0.6 mm, beam pitch 1.0, reconstruction interval 0.6 mm, and reconstruction function H90s. The field of view (FOV) was 150 mm, and the voxel size was 0.3 mm for the x- and y-axes and 0.6 mm for the z-axis. The scan was taken between the superior orbital margin and the maxillary alveolar process. The mid-sagittal plane was aligned with the mid-longitudinal axis of the guttry for scanning via parallel alignment of the scan and FH plane. The CT data were saved as DICOM files (Digital Imaging and Communications in Medicine).

The CT data were analyzed using measurement software (LANDmarker Direct, version 6.11; iCAT, Osaka, Japan). The lowest posterior point of the maxillary tuberosity (MT), the most lateral lowest point of the pterygomaxillary fissure (PF), the central lowest point of the alveolar crest through which the extended line of the infrrazygomatic crest passes (A), and the greater palatine canal (GPC) were defined (Fig. 1). The following distances were measured: (1) residual alveolar bone height: linear distance from point A to the maxillary sinus floor on the line perpendicular to the FH plane including point A in sagittal view (Fig. 1B); (2) MT–PF: the linear distance between the MT and the PF in panoramic view (Fig. 2); (3) MT–PF angle: the angle between the plane parallel to the FH plane including MT and the MT–PF line in panoramic view (Fig. 2); (4) A–PF: the linear distance between point A and the PF in panoramic view (Fig. 2); (5) A–PF angle: the angle between the plane parallel to the FH plane including point A and the A–PF line in panoramic view (Fig. 2); (6) PF–GPC: the shortest distance between the PF and GPC in axial view (Fig. 3).

Physical measurements
Using a lateral approach, a fan-shaped incision was made on the lateral part of the head of each sample to remove the temporal and masseter muscles. The zygomatic arch was then dissected at both ends of the masseter muscle, turned downwards, and removed. The mandibular ramus above the mandibular foramen was dissected, and the temporal muscle was turned upwards to identify the maxillary artery. Then, the vessels within the pterygopalatine fossa that were peripheral to the maxillary artery were identified and dissected, along with the MT and PF. Finally, soft tissues around the pterygopalatine fossa (excluding the vessel peripheral to the maxillary artery) were removed, leaving only the maxillary bone, the pala- tal bone, and the lateral plate of the pterygoid process of the sphenoid bone. The samples were placed on a flat experimental table with the FH plane parallel to the table surface. The shortest distances between the MT and the descending palatine artery (DPA) (MT–DPA), between the PF and DPA (PF–DPA), and between the alveolar crest and the posterior superior alveolar artery (PSAA) (AC–PSAA) were measured directly using a caliper (N10S; Mitutoyo Corporation, Kanagawa, Japan) (Fig. 4). ‘AC’ in the above ‘AC–PSAA’ indicates the point on the alveolar crest at which the distance between the alveolar crest and the PSAA is shortest. The shortest distance between point A and the DPA, as well as the distance between the PF and the greater palatine artery, could not be measured directly.

All CT and physical measurements were performed by a single expert examiner.

Statistical analysis
All statistical analyses were conducted using Excel 2002 (Microsoft Corporation, Redmond, WA, USA). P-values of <0.05 were considered statistically significant. Descriptive statistics of the measurement values were calculated for all samples, the male group, and the female group, respectively. An unpaired t-test was used for comparisons between the sexes.

Results
CT measurements
The mean and standard deviation values for all samples are presented in Table 1. The MT–PF was <15 mm in nine cases (15 hemi-heads), the A–PF was <15 mm
in one case (one hemi-head), and the PF–GPC was <2 mm in 19 cases (26 hemi-heads). There were no differences in measurements by sex (Table 2).

**Physical measurements**

The mean and standard deviation values for all samples are presented in Table 3. The MT–DPA was <15 mm in one case (two hemi-heads), the PF–DPA was <2 mm in four cases (five hemi-heads), and the AC–PSAA was ≤10 mm in one case (one hemi-head). There were no differences in measurements by sex (Table 4).

**Discussion**

Good clinical outcomes have been reported in studies by Rodriguez et al. and Balshi et al. using implants between 3.75 mm and 4.00 mm in diameter and between 15 mm and 18 mm in length. In another study, Rodriguez et al. reported that CBCT data from 202 cases showed that the average length from the tuberosity of the alveolar ridge to the most apical point of the pterygoid apophysis was 22.15 ± 1.56 mm. They also added that in most cases, a virtual implant of 15–18 mm in the pterygomaxillary region is appropriate if a safety distance of ≥2 mm is maintained between the implant and the pterygoid canal in the palate.

In this study, point A corresponded to the maxillary first and second molar region, similar to that reported in a study by Tahara. The distances MT–PF and A–PF in the present study corresponded to the length from the tuberosity of the alveolar ridge to the most apical point of the pterygoid apophysis in the study by Rodriguez et al., and the distance PF–GPC in the present study corresponded to their distance between the virtual pterygoid implant and the palatine artery.

In the present study, the mean MT–PF and A–PF values were 18.7 mm and 22.7 mm, respectively. The mean PF–GPC value was 2.9 mm. These mean values suggest that it is feasible to install a 15- to 18-mm long implant in the pterygomaxillary region, as reported in the studies by Rodriguez et al. However, the minimum values obtained in the present study were as follows: 10 mm for MT–PF, 14.7 mm for A–PF, 0.2 mm for PF–GPC, 12.7 mm for MT–DPA, 0.0 mm for PF–DPA, and 10 mm for AC–PSAA. These values suggest a potential danger in the placement of a pterygomaxillary implant of >15 mm, depending on the case.

The minimum values for MT–PF (10.0 mm), A–PF (14.7 mm), and PF–GPC (0.2 mm) obtained in this study are smaller than those reported in a study by Rodriguez et al. In that study, the length from the tuberosity of the alveolar ridge to the most apical point of the pterygoid apophysis was 15.4 mm and the distance between the virtual pterygoid implant and the palatine artery was 2.0 mm. This is likely due to differences in race, as the study of Rodriguez et al. used Caucasian subjects, while the present study used Japanese subjects. Past studies have shown that the anterior cranial base, maxillary length, and lateral plate length of the pterygoid process are less developed in
Table 1. CT measurement values for all samples (n = 78 hemi-heads); units are millimetres and degrees.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
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<tr>
<td>Residual alveolar height</td>
<td>5.9</td>
<td>2.5</td>
<td>1.2</td>
<td>9.9</td>
</tr>
<tr>
<td>MT–PF</td>
<td>18.7</td>
<td>3.9</td>
<td>10.0</td>
<td>26.3</td>
</tr>
<tr>
<td>MT–PF angle</td>
<td>75.1</td>
<td>8.1</td>
<td>56.2</td>
<td>90.0</td>
</tr>
<tr>
<td>A–PF</td>
<td>22.7</td>
<td>4.2</td>
<td>14.7</td>
<td>31.9</td>
</tr>
<tr>
<td>A–PF angle</td>
<td>52.3</td>
<td>13.8</td>
<td>22.3</td>
<td>79.9</td>
</tr>
<tr>
<td>PF–GPC</td>
<td>2.9</td>
<td>1.6</td>
<td>0.2</td>
<td>6.9</td>
</tr>
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</table>

CT, computed tomography; SD, standard deviation; MT, the lowest posterior point of the maxillary tuberosity; PF, the most lateral lowest point of the pterygomaxillary fissure; A, the central lowest point of the alveolar crest point through which the extended line of the infrazygomatic crest passes; GPC, the greater palatine canal.

Japanese populations than in Caucasian populations\(^{15-14}\). In addition, the northern Mongolian race (which includes the Japanese) has a higher rate of congenitally missing third molars than the Caucasian race\(^{15}\), which suggests poor development of the maxillary tuberosity area. Therefore, in the case of the patient of northern Mongolian race in whom the area with missing molars has a significantly resorbed alveolar process, the placement of implants with lengths \(\geq 15\) mm between the MT and point A in the alveolar crest

Table 2. CT measurement values by sex (male group: n = 42 hemi-heads; female group: n = 36 hemi-heads); units are millimetres and degrees.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Male</th>
<th>Female</th>
<th>T-value</th>
<th>P-value</th>
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<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>Residual alveolar height</td>
<td>6.1</td>
<td>2.5</td>
<td>1.2</td>
<td>9.9</td>
</tr>
<tr>
<td>MT–PF</td>
<td>18.4</td>
<td>4.3</td>
<td>10.0</td>
<td>26.3</td>
</tr>
<tr>
<td>MT–PF angle</td>
<td>75.1</td>
<td>8.9</td>
<td>56.2</td>
<td>90.0</td>
</tr>
<tr>
<td>A–PF</td>
<td>22.0</td>
<td>3.7</td>
<td>15.8</td>
<td>31.9</td>
</tr>
<tr>
<td>A–PF angle</td>
<td>54.3</td>
<td>13.9</td>
<td>24.3</td>
<td>79.9</td>
</tr>
<tr>
<td>PF–GPC</td>
<td>3.1</td>
<td>1.7</td>
<td>0.2</td>
<td>6.9</td>
</tr>
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</table>

CT, computed tomography; SD, standard deviation; MT, the lowest posterior point of the maxillary tuberosity; PF, the most lateral lowest point of the pterygomaxillary fissure; A, the central lowest point of the alveolar crest point through which the extended line of the infrazygomatic crest passes; GPC, the greater palatine canal.
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Table 3. Physical measurement values of all samples (n = 21 hemi-heads); units are millimetres.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT–DPA</td>
<td>19.4</td>
<td>3.9</td>
<td>12.7</td>
<td>27.0</td>
</tr>
<tr>
<td>PF–DPA</td>
<td>3.7</td>
<td>2.4</td>
<td>0.0</td>
<td>10.0</td>
</tr>
<tr>
<td>AC–PSAA</td>
<td>19.7</td>
<td>4.0</td>
<td>10.0</td>
<td>26.7</td>
</tr>
</tbody>
</table>

SD, standard deviation; MT, the lowest posterior point of the maxillary tuberosity; DPA, the descending palatine artery; PF, the most lateral lowest point of the pterygomaxillary fissure; AC, the alveolar crest; PSAA, the posterior superior alveolar artery.

Table 4. Physical measurement values by sex (male group: n = 13 hemi-heads; female group: n = 8 hemi-heads); units are millimetres.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
<th>T-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT–DPA</td>
<td>19.2</td>
<td>4.5</td>
<td>12.7</td>
<td>27.0</td>
<td>Male</td>
<td>19.8</td>
<td>3.1</td>
<td>14.8</td>
<td>24.4</td>
<td>2.1</td>
<td>0.7</td>
</tr>
<tr>
<td>PF–DPA</td>
<td>3.6</td>
<td>2.9</td>
<td>0.0</td>
<td>10.0</td>
<td>Female</td>
<td>3.9</td>
<td>1.5</td>
<td>1.6</td>
<td>6.0</td>
<td>2.1</td>
<td>0.7</td>
</tr>
<tr>
<td>AC–PSAA</td>
<td>19.4</td>
<td>4.3</td>
<td>10.0</td>
<td>26.7</td>
<td></td>
<td>20.2</td>
<td>3.8</td>
<td>14.8</td>
<td>26.3</td>
<td>2.1</td>
<td>0.7</td>
</tr>
</tbody>
</table>

SD, standard deviation; MT, the lowest posterior point of the maxillary tuberosity; DPA, the descending palatine artery; PF, the most lateral lowest point of the pterygomaxillary fissure; AC, the alveolar crest; PSAA, the posterior superior alveolar artery.

may result in serious complications if the implant direction is inappropriate, due to an insufficient bone quantity in the pterygomaxillary region. At present, this type of comparison by race is only possible between the Caucasian race and the northern Mongolian race because this study and those of Rodriguez et al. are the only available reports to date. A future study with a similar design and using samples of a different racial group is required to compare the results.

With regard to sex differences, previous studies have shown significantly higher values for some sites in the pterygomaxillary region in males compared to females. However, in the present study, the comparison by sex yielded no significant difference for any measurement, suggesting a need for future studies involving a larger sample size to reveal any sex-related differences.

In this study, a comparison of the mean CT measurement values of MT–PF and PF–GPC and the corresponding mean anatomical measurement values of MT–DPA and PF–DPA showed that the anatomical measurements presented higher values for all sites by approximately 1 mm compared to the CT measurements, irrespective of the sex. Therefore, the descending palatine artery may be located approximately 1 mm away from the PF when performing CT measurements preoperatively and intraoperatively during drilling from the maxillary tuberosity.

The mean MT–PF angle for all samples in this study was 75.1°, which is very similar to the angle of 74.19° obtained previously in one of the studies by Rodriguez et al. Graves reported that an implant guide hole should be placed in the maxillary second molar area with a 45° implant angle to the occlusal plane. In the present study, the mean A–PF angle relative to the FH plane was 52.3° for all samples. The occlusal plane in Japanese subjects is reported to incline forward by approximately 10° from the FH plane.

Thus, the mean A–PF angle relative to the occlusal plane would be 52.3° – 10° = 42.3°, which is in agreement with the pterygoid implant angle recommended by Graves and by Venturelli. Thus, the implant placement angles recommended previously may result in the implant extremely reaching the pterygopalatine fossa regardless of whether the drilling starts at MT or point A (located mesial to MT).

In conclusion, in the Japanese population, drilling may be started from the maxillary tuberosity at 75° to the FH plane at a depth of 15 mm, or from the A point (between the maxillary first and second molars) at 52° at a depth of 18 mm. However, considering individual anatomical variations, the drilling angle and depth should be decided carefully depending on the anatomical morphology of each respective case.

Funding
None.

Competing interests
None.

Ethical approval
Ethical approval was given by the Ethics Committee of Saga Medical School (approval number 27-17).

Patient consent
Not required.

References
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