

Clinicoanatomic Study on the Craniofacial Bones Used for Cranio- and Maxillofacial Implants

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Purpose: To clarify basic clinico-anatomic factors associated with cranio-maxillofacial rehabilitation using implants. **Materials and Methods:** Morphometrically evaluated were items such as the length and width of bone and the thickness of cortical bone at important sites for implant placement into cranial and maxillofacial bones in 30 cadavers at autopsy. **Results:** At sites corresponding to potential placement sites for implants as the fixation source for ocular epitheses, the mean length of bone was 7.8 mm, and the mean width was 8.3 mm. **Conclusion:** Useful data have been obtained for the selection of the placements sites, direction, length, and external diameter of cranio- and maxillofacial implants. (INT J ORAL MAXILLOFAC IMPLANTS 2002;17:121-129)

Key words: cadaver, clinico-anatomic study, cranio-maxillofacial implant

Cranio-maxillofacial implant prostheses have been used for the reconstruction of congenital or acquired cranio-maxillofacial morphologic abnormalities.¹⁻¹⁷ Placement of implants for the retention of bone-anchored hearing aids (BAHA) to address hearing impairment has also been advocated.^{2,4}

For the anchorage of cranio-maxillofacial implants, the amount and quality of bone should be adequate at the implant placement site.¹⁸ However, to the authors' knowledge, there has been only 1 clinico-anatomic study on cranial bones at potential placement sites which morphometrically evaluated the periorbital bones, zygomatic bone, and maxilla.⁹

To provide information pertinent to bone quantity at potential implant sites, measurements were made of resected cadaver specimens and compared.

MATERIALS AND METHODS

Japanese cadavers presented for autopsy (30 cadavers, 30 sides; aged 42 to 94 years) were fixed with 70% alcohol after infusion of 10% formalin (about 6 liters) via a femoral artery (Table 1). Various bones such as those constituting the orbital margin, temporal bone, and maxilla were resected using the median line (connecting the superior margin and the anterior nasal spine) as a reference. As bones constituting the orbital margin, the following specimens (left side, 23; right side, 7) were used for measurement: a 2-cm area from the orbital margin (medial surface of orbit); a maximum of 3-cm areas of the frontal, zygomatic, maxillary, lacrimal, and nasal bones (frontal surface of the orbit) in the superoinferior and mediolateral directions (Fig 1). For measurement of the temporal bone, the bone area 3 cm from the external acoustic foramen was resected from the external surface to the internal surface (right side, 4; left side, 10; Fig 2). For measurement

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of the frontal bone and nasal bone, a sagittal section at a site 5 mm lateral to the median line was obtained as the median site (right side, 5; left side, 19; Fig 3). For measurement of the maxilla, the area at the alveolar and palatine processes from the median line to its parallel line passing the most lateral margin of the piriform opening was resected (right side, 2; left side, 13; Fig 4). Each bone specimen was resected using an electric plaster cutter after removal of the soft tissue using a scalpel. The number of specimens differed according to sites and between the right and left sides. Cadavers that had antemortem diseases markedly affecting bone were excluded.

Table 1 Patient Distribution with Regard to Age and Gender

Age (y)	Male	Female	Total
40-49	1	0	1
50-59	4	2	6
60-69	4	1	5
70-79	4	1	5
80-89	3	7	10
90+	2	1	3
Total	18	12	30

Range of age: 42-94 years; average age: 73 years.

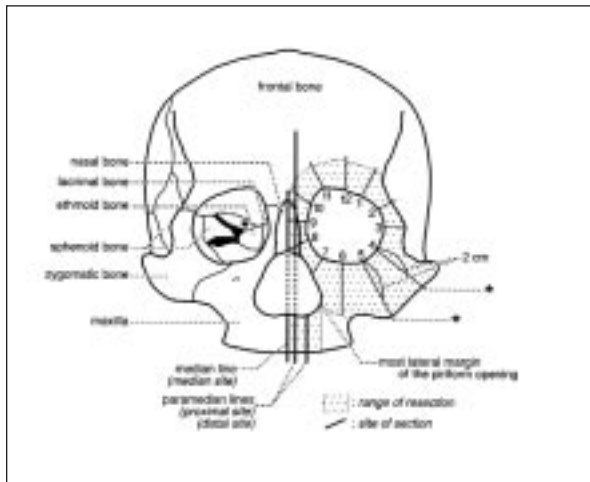


Fig 1 Bones constituting the orbital margin and the range of observation. (The picture is drawing left side.) 1:00 to 12:00: With the center of the orbit as a reference point, the orbital margin was divided into 12 equal areas (12:00, 1:00 to 11:00) clockwise on the left side and counterclockwise on the right side). * = site 2 cm lateral to the superomedial margin of the zygomatic bone at 4:00 and 5:00. Proximal site = site 5 mm lateral to the median line of the maxilla. Distal site = site 5 mm medial to the most lateral margin of the piriform opening. Median line = line linking the midpoint in the superior margin of the nasal bone and the anterior nasal spine. Paramedian site = site in the frontal bone and nasal bone 5 mm lateral to the median line.

Each measurement site was cut using a diamond disc. The length, width, and the thickness of cortical bone were measured using vernier calipers. The mean values on the right and left sides at the same site were determined. At each measurement site, soft tissue was removed, and the same examiner determined the measurement sites and performed the measurement.

Measurement Sites

The median line was shifted parallel to the midpoint between the most medial and lateral margins of the orbit. Using the center of the orbit as a reference point, its upward direction was 12:00 and its downward direction was 6:00. The orbital margin was divided into 12 equal areas (1:00 to 12:00 clockwise on the left side and counterclockwise on the right side). Measurements were made on each section at the 12 sites. At 12:00 and 1:00 to 5:00, which are frequently used as sites for implant placement, the length and width of bone and the thickness of cortical bone were measured. At 6:00 to 11:00, only the length of bone was measured (Fig 1).

At 1:00 and 12:00, the length of bone was regarded as the shortest distance between the supra-orbital margin and the cranial base, or the base of the frontal sinus when observed on the section. For measurement of the width of bone, a line perpendicularly

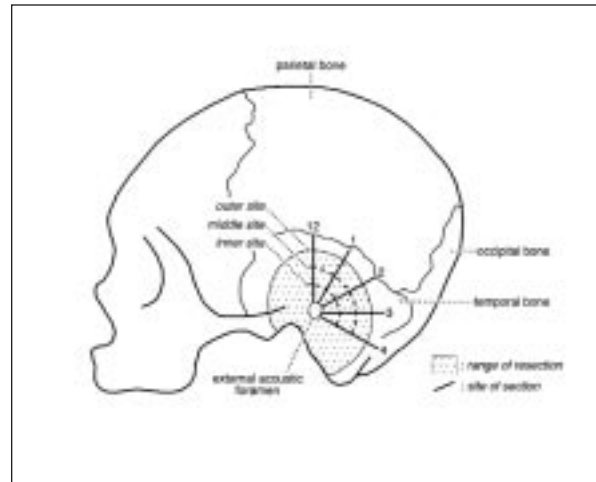


Fig 2 Range of observation in the temporal bone. The temporal bone was divided into 12 equal areas using the center of the external acoustic foramen as a reference point (observation range: 12:00, 1:00 to 4:00). Inner site = 15 mm from the superior or lateral wall of the external acoustic foramen in the direction of the parietal or occipital margin. Middle site = 20 mm from the superior or lateral wall of the external acoustic foramen in the direction of the parietal or occipital margin. Outer site = 30 mm from the superior or lateral wall of the external acoustic foramen in the direction of the parietal or occipital margin.

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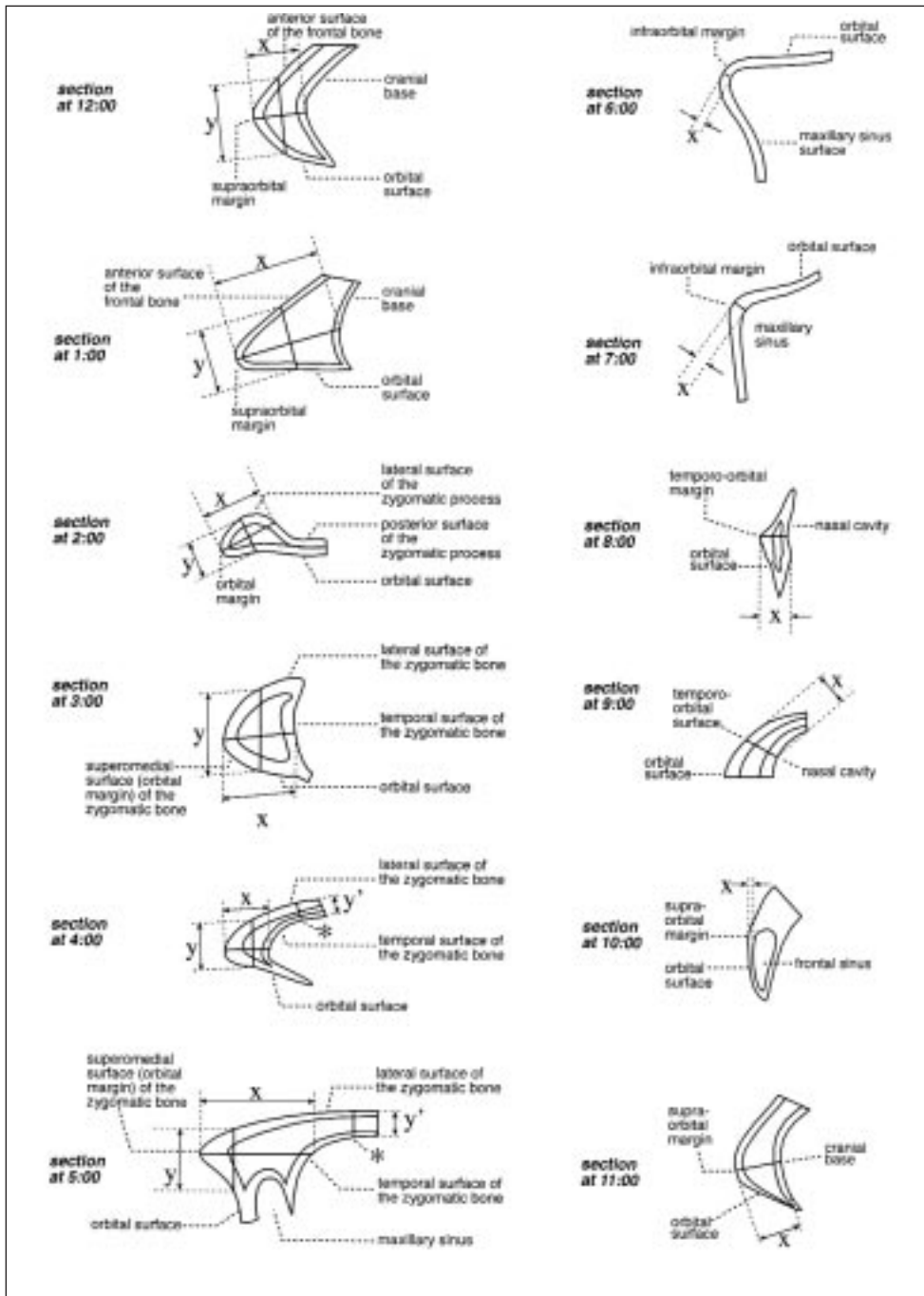


Fig 3 Measurement sites in each section of bones constituting the orbit. X = length, Y = width. * = 2 cm lateral to the orbital margin.

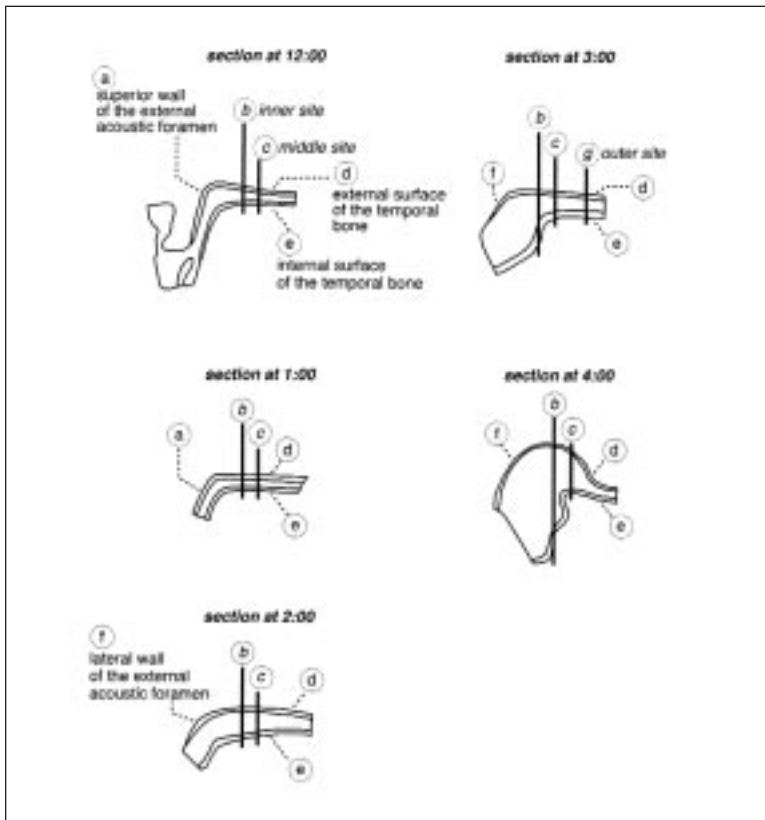


Fig 4 Site for measurement of length on each section of the temporal bone.

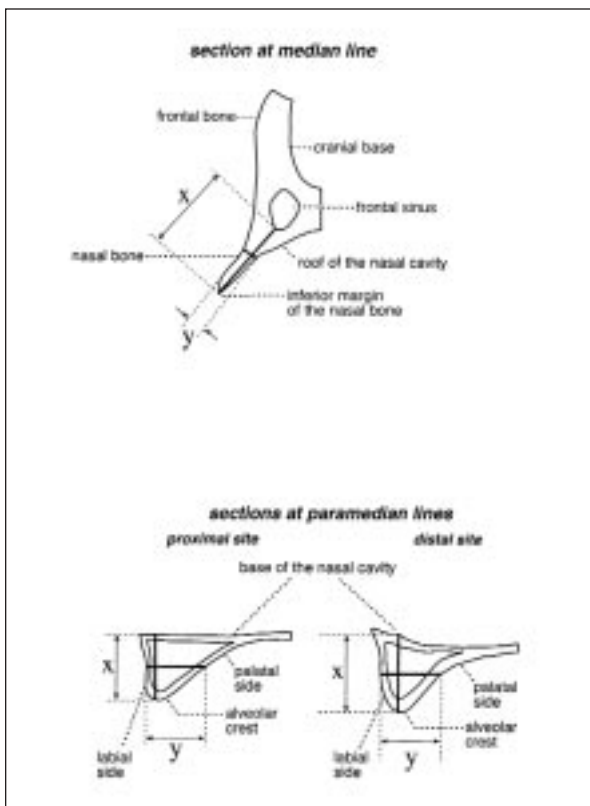


Fig 5 Measurement sites on the section of the frontal bone and nasal bone, and measurement sites on each section of the maxilla. X = length, Y = width.

intersecting the bone length at its 1/2 point was drawn, and the distance between the 2 intersecting points of this line on the anterior surface of the frontal bone and on the orbital surface was defined as width. At 2:00, the distance between the orbital margin of the zygomatic process of the frontal bone and the temporal surface of the frontal bone was considered to be length. At 3:00, the shortest distance from the superomedial margin (orbital margin) of the zygomatic process to the temporal surface of the zygomatic bone was regarded as length. Bone width was defined as the distance between the 2 points at which a line perpendicularly crossing the midpoint of the length intersected the lateral surface of the temporal or zygomatic bone and the orbital surface. At 4:00 and 5:00, the shortest distance between the superomedial margin (orbital margin) of the zygomatic process and the temporal surface was measured as length, and the distance between the 2 points at which a line perpendicularly crossing the midpoint of the length intersected the lateral surface and the orbital surface was measured as width. In addition, at the site 2 cm lateral to the superomedial margin (orbital margin) of the zygomatic bone, the shortest distance between the lateral surface and temporal surface was measured as width.

On the right side, the thickness of cortical bone was measured at each measurement site for length

Table 2 Length and Width of Bone Constituting the Orbital Margin and the Thickness of Cortical Bone and Differences

Measurement site	Length	Width	Thickness of cortical bone
12	9.9 ± 3.3	8.5 ± 2.1	2.4 ± 0.6
1	16.0 ± 3.1	8.8 ± 2.0	2.5 ± 0.6
2	9.5 ± 1.9	6.8 ± 1.1	2.4 ± 0.6
3	9.2 ± 1.4	9.3 ± 1.6	2.4 ± 0.5
4	10.0 ± 2.6	9.9 ± 1.7	2.1 ± 0.7
4a	—	5.0 ± 1.7	—
5	11.7 ± 3.7	11.1 ± 3.3	2.1 ± 0.6
5a	—	7.2 ± 1.7	—
6	6.0 ± 2.6	—	—
7	4.3 ± 2.0	—	—
8	4.4 ± 1.1	—	—
9	4.3 ± 1.5	—	—
10	3.0 ± 1.6	—	—
11	5.0 ± 3.1	—	—
Average	7.8 ± 2.3	8.3 ± 1.9	2.3 ± 0.6

All measurements (in mm) reflect mean ± SD.

— = Not measured.

4a = Zygomatic bone 2 cm from the orbital margin at 4:00.

5a = Zygomatic bone 2 cm from the orbital margin at 5:00.

Table 3 Differences in Length and Width of the Temporal Bone and the Thickness of Cortical Bone

	Measurement site					Average
	12	1	2	3	4	
Length						
Inner site	4.0 ± 1.1	9.2 ± 5.4	14.3 ± 5.2	13.0 ± 4.2	15.5 ± 6.6	11.2 ± 4.5
Middle site	2.8 ± 0.5	8.0 ± 5.9	10.4 ± 3.0	10.4 ± 3.2	10.1 ± 3.5	8.3 ± 3.2
Outer site	—	—	—	8.6 ± 3.4	—	—
Results of test	*	*	*	*	*	—
Thickness of cortical bone						
Inner site	1.6 ± 0.4	3.0 ± 1.5	3.7 ± 1.3	3.5 ± 1.0	2.9 ± 1.0	3.0 ± 1.0
Middle site	1.3 ± 0.3	2.7 ± 1.1	3.7 ± 1.2	3.4 ± 1.1	2.7 ± 1.2	2.7 ± 1.0
Outer site	—	—	—	3.0 ± 0.9	—	—
Results of test	*	*	*	*	*	—

All measurements (in mm) reflect mean ± SD.

— = Not measured.

**P* < .05.

Table 4 Length and Width of the Maxilla and the Median Site of the Frontal and Nasal Bone Plus Thickness of Cortical Bone

	Maxilla			Midline of frontal bone and nasal bone
	Medial site	Distal site	Results of test	
Length	13.6 ± 6.0	12.5 ± 6.3	NS	19.3 ± 9.7
Width	10.1 ± 3.2	8.1 ± 2.7	*	5.6 ± 2.6
Thickness of cortical bone	1.4 ± 0.6	1.3 ± 0.4	NS	3.0 ± 1.4

All measurements (in mm) reflect mean ± Sd.

SD = standard deviation; NS = not significant.

**P* < .05.

and width at 12:00 and 1:00 to 5:00, and the mean values were used as results (Figs 1 and 3). At 6:00, the shortest distance between the superomedial margin (infraorbital margin) of the zygomatic bone or the infraorbital margin of the maxilla and the maxillary sinus surface was measured as length. When the infraorbital foramen was observed on the section, measurement was made at a site 5 mm lateral to the foramen. At 7:00 to 9:00, the shortest distance from the medial orbital margin of the maxilla to the maxillary sinus surface or nasal surface was measured as length. At 10:00 and 11:00, the shortest distance between the supraorbital margin of the frontal bone and the cranial base, or the base of the frontal sinus when it was observed on the section, was measured as length (Figs 1 and 3).

For measurement of the temporal bone region, the median line was shifted parallel to the center of the external acoustic foramen, and its upward direction was defined as 12:00, and its downward direction as 6:00. The temporal bone region was divided into 12 equal areas. Measurement was made on each section at 5 sites from 12:00 to 4:00 (clockwise on the left side and counterclockwise on the right side; Fig 2).

As length, the distance between the internal and external surface of the temporal bone was measured at a site 15 mm (inner site) and 20 mm (middle site) from the superior or lateral wall of the external acoustic foramen in the direction of the parietal or occipital margin. At 3:00, length was also measured at a site 30 mm (outer site) from the lateral wall of the external acoustic foramen. The thickness of cortical bone was measured at each site for the measurement of length (Figs 2 and 4).

Median Site of the Frontal Bone and Nasal Bone. The site 5 mm lateral to the median line was defined as the median site and its sagittal section was measured. As length at the median site, the shortest distance between the inferior margin of the nasal bone to the base of the frontal sinus was measured. The width at the median site was defined as the distance between the 2 points at which a line perpendicularly crosses the length at its midpoint, intersecting the lateral surface of the frontal bone or nasal bone and the nasal cavity side of the frontal bone. The thickness of cortical bone was measured at each site for the measurement of length and width, and the mean value was used as a result (Figs 1 and 5).

Maxillary Region. The maxilla was measured on a sagittal section at a site 5 mm lateral to the median line (proximal site) and on a sagittal section at a site 5 mm medial to the most lateral margin of the piriform opening (distal site). Length was defined as the shortest distance between the base of the nasal

cavity and the alveolar crest. Width was regarded as the distance between the 2 points at which a line perpendicularly crosses the length at its midpoint, intersecting the labial side and palatal side of the maxilla. The thickness of cortical bone was measured at each site for the measurement of length and width (Figs 1 and 5). Specimens showing teeth on sections were excluded from measurement.

Statistical Analysis of Measurement Values. The same examiners made each measurement recording 3 times, and the mean value was obtained. Differences among the measurement sites were analyzed by Bartlett test. Differences between the right and left sides were not analyzed because of the small number of specimens.

RESULTS

Orbital Region

Length. The value at 1:00 (16.0 mm) was the highest, followed in order by 5:00, 4:00, 12:00, 2:00, and 3:00; the value at 10:00 (3.0 mm) was the lowest (Table 2, Fig 3). The values at 6:00 to 1:00, corresponding to the infraorbital-lateral orbital margin, were significantly lower than those at 12:00 and 1:00 to 5:00, corresponding to the supraorbital-lateral orbital margin. Among 6:00 to 11:00, the value at 10:00 was significantly low. Among 12:00 and 1:00 to 5:00, the value at 1:00 was significantly high (Table 2, Fig 3).

Width. The value at 5:00 (11.1 mm) was the highest, followed in order by that at 4:00, 3:00, 1:00, 12:00. The value at 2:00 (6.8 mm) was the lowest. At the site of the zygomatic bone 2 cm lateral to its superomedial margin (orbital margin), the value at 5:00 (7.2 mm) was higher than that at 4:00 (5.0 mm) (Table 2, Fig 3). For the 12:00 and 1:00 to 5:00, the value at 5:00 was the highest, and that at 2:00 was the lowest (Table 2, Fig 3).

Thickness of Cortical Bone. The value at 1:00 (2.5 mm) was highest, followed by that at both 2:00 and 3:00, and the values at 4:00 and 5:00 (2.1 mm) were the lowest (Table 2, Fig 3).

Among the measurement sites, the values at 4:00 and 5:00 were significantly lower than those at 12:00 and 1:00 to 3:00 (Table 2, Fig 3).

Temporal Bone Region

Length. At the inner site, the value at 4:00 (15.5 mm) was the highest, followed in order by 2:00, 3:00, and 1:00. The value at 12:00 (4.0 mm) was the lowest. At the middle site, the value at 2:00 and 3:00 (10.4 mm) was the highest, followed in order by that at 4:00 and 1:00; the value at 12:00 (2.8 mm)

was the lowest. At the outer site, the value at 3:00 was 8.6 mm (Table 3, Fig 4).

Among the 1:00 to 3:00 and 12:00 positions, the value at 12:00 was significantly low both at the inner and middle sites. No significant differences were observed among 2:00, 3:00, and 4:00. Among the inner, middle, and outer sites, the value significantly decreased with an increase in the distance from the external acoustic foramen (Table 3, Fig 4).

Thickness of Cortical Bone. At the inner site, the value at 2:00 (3.7 mm) was the highest, followed in order by that at 3:00, 1:00, and 4:00, and the value at 12:00 (1.6 mm) was the lowest. At the middle site, the value at 2:00 (3.7 mm) was the highest, followed in order by that at 3:00, 1:00, and 4:00, and the value at 12:00 (1.3 mm) was the lowest. At the outer site, the value was 3.0 mm (Table 3, Fig 4).

Median Site of the Frontal Bone and Nasal Bone

At the median site of the frontal and nasal bones, the length of bone was 19.3 mm, the width of bone was 5.6 mm, and the thickness of cortical bone was 3.0 mm (Table 4, Fig 5).

Maxillary Region

In the maxillary region for the range observed in this study, the length of bone was 13.6 mm at the proximal site and 12.5 mm at the distal site. Its width was 10.1 mm at the proximal site and 8.1 mm at the distal site. The thickness of cortical bone was 1.4 mm at the proximal site and 1.3 mm at the distal site.

Among the sites of measurement, no significant differences were observed in bone length nor cortical bone thickness. The bone width was significantly higher at the proximal site (Table 4, Fig 5).

DISCUSSION

Measurement Methods

Jensen and associates⁹ reported the thickness of bones around the orbit and around the external acoustic foramen, but did not describe the measurement methods. In studies by Shimizu¹⁹ and Matsuura and coworkers,²⁰ the same examiner performed bone measurements on a scapular flap with a free bone and a free fibular flap with vascular pedicle, respectively, after the removal of surrounding soft tissue. Three measurements were made using vernier calipers and the mean values were obtained. In this study, the soft tissue was removed to expose the bone surface by the method of Shimizu¹⁹ and Matsuura and colleagues,²⁰ and the length and width of bone and thickness of cortical bone were measured.

Orbital Region. Three or 4 mm flame implants used for cranial and maxillofacial implants may be used in the orbital margin.^{2,4,6,12-15} Jensen and colleagues⁹ measured the length of bone at 5 sites (2 sites in the supraorbital margin, 2 in the lateral orbital margin, and 1 in the infraorbital margin) and reported the mean bone length at these sites to be 4.4 and 4.6 mm, 5.9 and 6.1 mm, and 4.5 mm, respectively. In the present study, the mean length was more than 9 mm at 12:00 in the supraorbital margin, at 1:00 to 5:00 in the lateral orbital margin, and 6 mm at 6:00 in the infraorbital margin. These values were higher than those reported by Jensen and colleagues.⁹ Since the length of bone was more than 6 mm at 12:00 and 1:00 to 5:00, the flame implant in the Brånemark system (Nobel Biocare, Göteborg, Sweden) may be applicable at these sites. On the other hand, at 6:00 to 11:00 corresponding to the infraorbital margin, the bone length was relatively low, and implant placement would require careful attention. The thickness of bone at the site of implant placement could be identified in more detail than Jensen and colleagues⁹ by dividing the orbital margin into small areas.

To the authors' knowledge, there have been no studies on the width of bone and the thickness of cortical bone. In this study, the width of bone was lowest in the lateral orbital margin, but was more than 6 mm at each site, suggesting that implant placement is possible. At 4:00 and 5:00, the mean width in the zygomatic bone site 2 cm lateral to the orbital margin was 5 mm or more, indicating that implant placement into these sites is also possible. The implant placement sites for fixation of ocular epitheses differs among institutions. Since peri-orbital bones have been evaluated in detail after dividing the periorbital margin into small areas, the present measurement results may provide useful data for selection of implants and their placement site.

Temporal Bone. Concerning implant placement sites in the bone for the retention of auricular epitheses, Tjellstrom⁴ reported that an implant 3 to 4 mm in length can be placed into a site about 18 mm posterior to the center of the external acoustic foramen. Lundgren and associates¹⁰ reported that they generally place an implant (4 mm in length) for the fixation of BAHA into a site about 25 mm posterior to the center of the external acoustic foramen at 9:00 on the right side and at 3:00 on the left side.

Jensen and coworkers⁹ reported that the mean thickness of the temporal bone approximately 15 mm posterior to the center of the external acoustic foramen was about 8.8 mm. In the present study, the values at 1:00 to 4:00 were similar or higher than those reported by Jensen and coworkers,⁹ but

the value at 12:00 was lower. Tjellström⁴ placed implants at sites corresponding to 1:00 and 3:00 in the present study for the retention of auricular epitheses. However, bone appears to be adequately thick at 2:00 and 4:00 for implant placement. The bone width decreased with an increase in the distance from the external acoustic foramen. Therefore, for the placement of long implants, the area 15 to 20 mm from the external acoustic foramen may be appropriate.

At the distal site at 3:00, corresponding to the implant placement site for implants supporting BAHA, the length of bone and thickness of cortical bone appeared to be adequate for the placement of 4-mm implants. The thickness of cortical bone has not been previously reported, but was clarified in this study.

Median Site of the Frontal Bone and Nasal Bone. The results in this study showed that placement of cranio-maxillofacial implants for the support of epitheses for defects in the nose or midface is possible in the median area of the frontal bone and nasal bone.

Maxillary Region. For the support of epitheses for facial defects, dental implants or cranio-maxillofacial implants are sometimes placed from the nasal cavity side or labial side of the maxilla.^{7,9,14} Jensen and associates⁹ reported the mean thickness of alveolar bone from the base of the nasal cavity to the root apex of anterior teeth to be 10.2 mm, suggesting that implants with a length of 6 mm or more can be placed. Cawood and Howell²¹ reported that the mean length between the anterior nasal spine and the alveolar crest was about 19 mm in 30 dry cranial bone specimens with anterior tooth defects in the median area. Lang and Baumeister²² reported that the thickness of alveolar bone in the incisive canal areas was 11.6 mm in 149 autopsy cases.

Comparison between the results of the present study and those in previous studies is inappropriate because of different sites of measurement. However, the length of bone in the present study was generally higher than the values reported by Jensen and colleagues,⁹ but lower than that reported by Cawood and Howell.²¹ The width of bone in the present study was higher than that reported by Lang and Baumeister.²² The length of bone did not differ significantly among the measurement sites in the present study. However, the width of bone was higher at the proximal site than at the distal site in the lateral margin of the piriform opening. Therefore, when dental implants or cranio-maxillofacial implants are placed from the lateral side, longer implants can be placed on the median side.

CONCLUSION

To clarify basic clinicoanatomic information concerned with the placement of maxillofacial implants into cranio-maxillofacial bones, various cranial and facial bones in cadavers were morphometrically analyzed with the following results.

Orbital Region

At sites corresponding to potential placement sites for implants as the fixation source for ocular epitheses, the mean length of bone was 7.8 mm, and the mean width was 8.3 mm.

Temporal Bone Region

At the middle site corresponding to the potential placement site of implants for the support of auricular epitheses, the mean length was 8.3 mm. At the outer site at 3:00 corresponding to the potential placement site for implants supporting BAHA, the length of bone was 8.6 mm, and the thickness of cortical bone was 3.0 mm.

Median Site of the Frontal Bone and Nasal Bone

At the median site of the frontal bone and nasal bone, a potential placement site for implants retaining nasal and facial epitheses, the length of bone was 19.3 mm, the width of bone was 5.6 mm, and the thickness of cortical bone was 3.0 mm.

Maxillary Region

At the proximal and distal sites corresponding to potential placement sites for implants from the nasal cavity or labial side as a fixation source for dental implants or cranio-maxillofacial epitheses, the width of bone at the proximal site (10.1 mm) was significantly higher than that at the distal site, but the length of bone (13.6 mm) and the thickness of cortical bone (1.4 mm) did not significantly differ between the proximal and distal sites.

Useful data have been obtained for the selection of the placement sites, direction, length, and external diameter of dental implants and cranio-maxillofacial implants used in the maxilla.

ACKNOWLEDGMENTS

The authors thank Reiji Takiguchi, Professor Emeritus at Showa University School of Dentistry, and Dr Harunobu Shima, for collaborating with the research.

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