Internal Structure of Zygomatic Bone Related to Zygomatic Fixture

Yorihisa Kato, DDS, PhD, Yasuhiro Kizu, DDS, PhD,†
Morio Tonogi, DDS, PhD,‡ Yoshinobu Ide, DDS, PhD,§ and
Gen-yuki Yamane, DDS, PhD‖*

Purpose: The purposes of this study were to investigate the internal structure of the edentulous zygomatic bone, which provides anchorage for the zygomatic fixture, using micro–computed tomography, and to examine the relation between the internal structure of the edentulous zygomatic bone and the zygomaticus fixture.

Materials and Methods: Twenty-eight zygomatic bones of edentulous maxillae from cadavers were used. The mean age of cadaver specimens was 79.6 years. The specimens were analyzed using micro–computed tomography.

Results: The internal structure of edentulous maxillae had thicker trabeculae in the region at the tip of the zygomaticus fixture than in other regions.

Conclusions: The present findings suggest that the presence of wider and thicker trabeculae at the end of the fixture promotes initial fixation. Also, when the trabeculae are able to support occlusal force after successful osseointegration, this thickening greatly aids the support of the fixture at the tip of the fixture, where stress is thought to be concentrated. In addition, the occlusal force was applied to the entire zygomatic bone. This preliminary study suggests that better understanding of the internal structure of the zygomatic bone will provide further information about the direction of installation of the zygomatic fixture, the ideal position of the zygomatic fixture, and the prognosis of implant therapy.

J Oral Maxillofac Surg 63:1325-1329, 2005

Oral implants were first applied clinically in 1965 and are currently recognized as an excellent option for prosthetic treatment of defects.[1,2] Implants that integrate into bone without fibrous tissue formation in the interface are widely regarded as the most reliable.[3] Maxillary implants are often inserted between the right and left canines. Placement in the region of the maxillary molars provides good occlusal stability, although this is often difficult due to complications such as the presence of the maxillary sinus and decreased bone volume in the maxillary molars. In recent years, maxillary sinus lift, in which the sinus floor is elevated by autologous bone grafting, has been performed.[4] The disadvantages of this method are surgical invasion at the site of autologous bone collection, the relatively long treatment period, and poor long-term outcome of the bone graft.

In 1989, a zygomatic fixture was developed for anchoring implants into the zygomatic bone and maxillary alveolar bone.[5] Figure 1 shows the position of a zygomatic fixture. The zygomatic fixture is an extended length (35 to 50 mm) titanium implant placed through the palatal aspect of the resorbed posterior maxilla, transantrally into the compact bone of the zygomatic bone. Using this fixture, autologous bone grafting can be avoided and the treatment period shortened. In addition, existing bone can be used for fixture anchorage.

When using implants, occlusal force applied to the superstructure is mainly supported by cortical and cancellous bones.[6] Thus, it is important to understand the internal structure of the jawbone, which is thought to be closely involved in support of the im-

Received from the Tokyo Dental College, Ichikawa-city, Chiba, Japan.

*Graduate Student, Department of Oral Medicine.

†Assistant Professor, Department of Oral Medicine.

‡Associate Professor, Department of Oral Medicine.

§Professor, Department of Anatomy.

‖Professor, Department of Oral Medicine.

This research was supported in part by the Department of Anatomy, Tokyo Dental College.

Address correspondence and reprint requests to Dr Kato: Department of Oral Medicine, Tokyo Dental College, 5-11-13 Sugano, Ichikawa-city, Chiba 272-8513, Japan; e-mail: yoriyorikatou@yahoo.co.jp

0278-2391/05/6309-0012$30.00/0
doi:10.1016/j.joms.2005.05.313

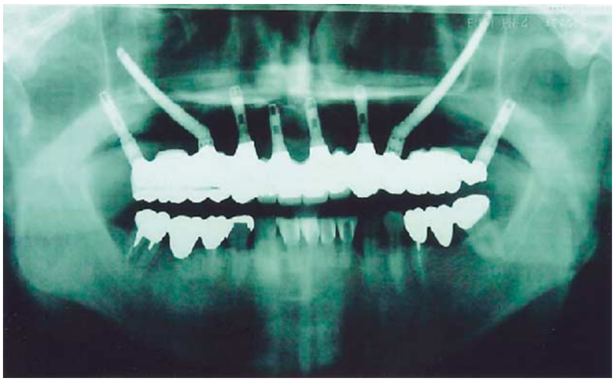

FIGURE 1. Panoramic appearance of 4 anterior and 2 posterior maxillary implants in combination with 2 zygomatic fixtures.

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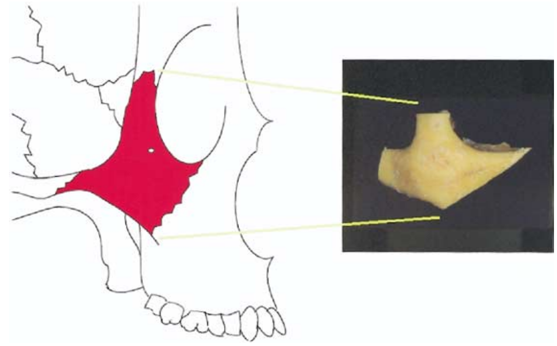

FIGURE 2. Schematic diagram of zygomatic bone (*right*) and a specimen from a cadaver skull (*at right*). The specimens were obtained from the skulls of cadavers, from the sutura frontozygomatica, posterior to the sutura temporozygomatica down to the sutura zygomaticomaxillaris.

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plant. However, there have been no reports of basic studies of zygomatic fixtures or anatomical studies of the relationship between such fixtures and the internal structure of the zygomatic bone.

There have been many reports on the internal structure of bones. In most such studies, test specimens were embedded, thin sections were prepared, and 2-dimensional soft x-ray images were obtained.[7] Using such a method, it is difficult to evaluate the 3-dimensional structure of bone and obtain information about the margin for cutting. Some recent studies have analyzed 3-dimensional bone specimens using a micro–computed tomography (micro-CT) system, which allows not only nondestructive serial imaging of specimens but also 3-dimensional reconstruction.[8,9] In the present study, we used micro-CT to analyze the 3-dimensional internal structure of the zygomatic bone that provided anchorage for a zygomatic fixture and examined the relationship between the internal structure of zygomatic bone and the zygomatic fixture.

Materials and Methods

Twenty-eight zygomatic bones from human edentulous maxillae obtained from the Department of Anatomy, Tokyo Dental College, were cleaned of all soft tissue and fixed in 10% neutralized buffered formalin solution. The mean age of the cadavers was 79.6 years. The specimens were obtained from the sutura frontozygomatica, posterior to the sutura temporozygomatica down to the sutura zygomaticomaxillaris (Fig 2).

To visualize the 3-dimensional bone structure, we performed micro-CT (KMS-755; Kashimura Inc, Tokyo, Japan) (Fig 3). The main imaging apparatus consisted of an x-ray generator, specimen stage, and detector. The focus size of the x-ray generator was 6 × 8 μm. A tube voltage ranging from 20 to 80 kV could be generated, and the tube current ranged from 0 to 100 A. X-rays were emitted at 55 kV and 100 A. The detector was equipped with a 4-inch-long image intensifier tube and a 1-inch-long CCD camera with a scanning line of 1024 × 1024 and was capable of outputting 500 bits of raw data, 16 bits at a time. Based on the raw data obtained, 2-dimensional slice images were produced by the back-projection method. Three-dimensional reconstruction was performed using 200 of these 2-dimensional images processed by the volume rendering method (Fig 4).

Figure 5 shows the position of a zygomatic fixture in a male cadaver. To investigate internal structure around the zygomatic fixture, 2 anthropological reference points were used: the jugale (Ju) at the most concave point between the lateral margin of the upper zygomatic bone and the upper margin of the zygomatic arch and the zygomaxillare (Zm) at the lowermost point of the zygomaticomaxillary suture (Fig 6).

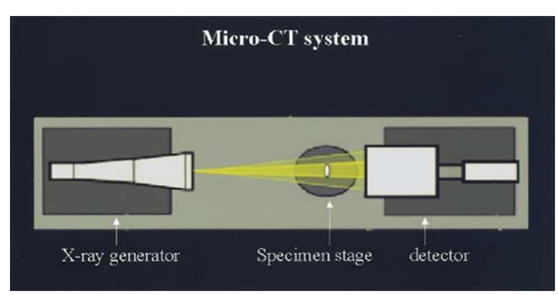

FIGURE 3. Schematic diagram of the present micro-CT method. The system consists of a main imaging apparatus and a computer. This system can be used to analyze the whole mandible. The main imaging apparatus consists of an x-ray generator, specimen stage, and detector.

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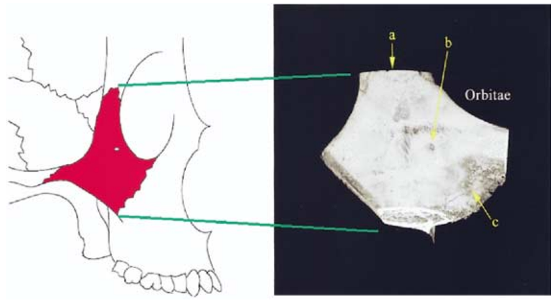

FIGURE 4. Three-dimensional reconstruction of a right zygomatic bone. *A*, Frontal process. *B*, Zygomaticofacial foramen. *C*, Zygomaticomaxillary suture.

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We divided the zygomatic bone into 3 regions: around Ju, around Zm, and around the midpoint between Ju and Zm (M.P.). We designated 3 volumes of interest (VOIs) in each region (Fig 7). The VOIs did not include cortical bone. The size of each VOI was 80 × 80 × 80 pixels.

We calculated the morphology parameters in each region by counting voxels from the 3-dimensional images. The micro-CT unit produced a report of microstructural data in 3 dimensions. The parameters in this analysis were bone volume density (BV/TV), trabecular plate thickness (Tb.Th), trabecular plate number (Tb.N), and trabecular plate separation (Tb.Sp).

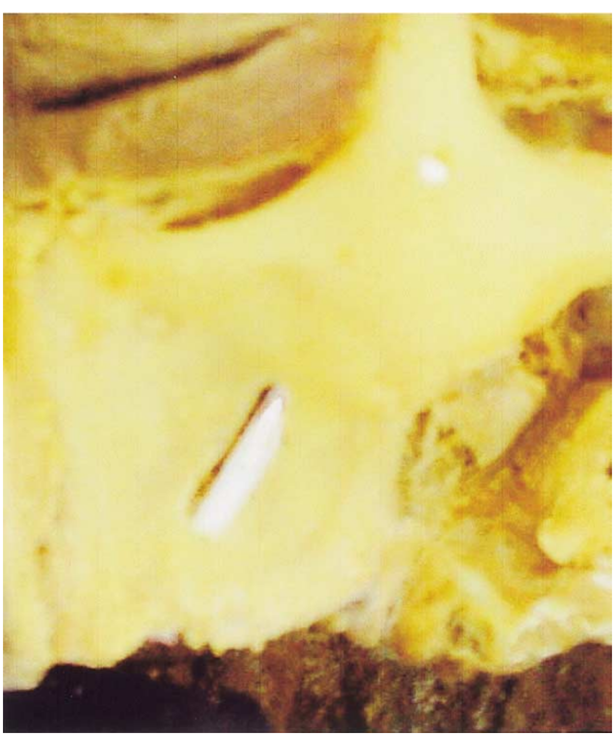

FIGURE 5. Anatomic model of zygomatic fixture placed through the palatal side of the second premolar, transantrally, into the compact bone of the zygoma.

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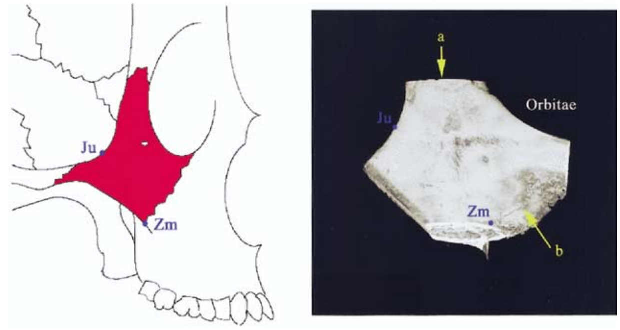

FIGURE 6. We used 2 anthropological reference points: the jugale (Ju) at the most concave point between the lateral margin of the upper zygomatic bone and the upper margin of the zygomatic arch and the zygomaxillare (Zm) at the lowermost point of the zygomaticomaxillary. *A*, Frontal process. *B*, Zygomaticomaxillary suture.

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Comparisons of VOI parameters in each region were performed using Student's *t* test. Standard deviations of measurement were also calculated.

Results

A total of 56 sites in zygomatic bone from edentulous maxillae were evaluated. Trabecular bone from each region is shown in Figure 8. Visual observation of the reconstruction clearly showed that the trabeculae were thicker in the Ju region than in the other regions. Trabeculae in the Ju region consisted of a plate-like structure. Trabeculae in the mid-point region and Zm region contained fewer and thinner trabeculae elements than trabeculae in the Ju region. Many of the connecting rods were missing.

The conclusions of our morphometric analyses are presented in Table 1. Bone volume density was higher in the Ju region than in the other regions. Also, tra-

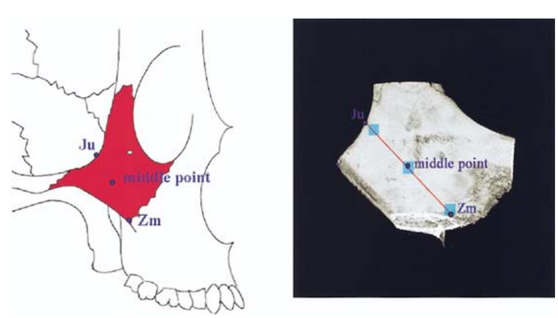

FIGURE 7. The zygomatic bone was divided into 3 regions: around the Ju, around the Zm, and around the midpoint between Ju and Zm. A schematic representation of the positions of the 3 volumes of interest in the zygomatic bone is shown.

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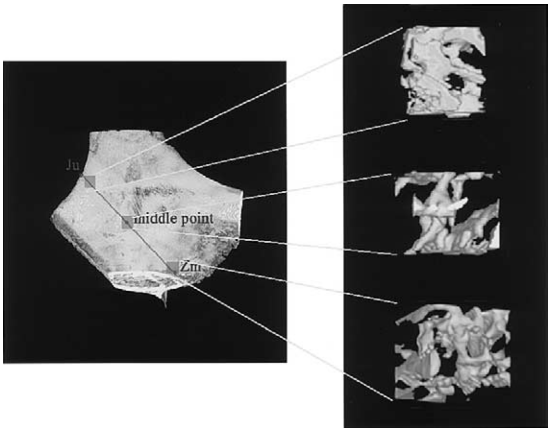

FIGURE 8. Three-dimensional reconstruction of the trabecular bone from 3 volumes of interest in the zygomatic bone. Visual observation of the reconstruction clearly showed that the trabeculae were thicker in the Ju region than in other regions.

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becular plate thickness and trabecular plate number were greater in the Ju region than in the other regions. Examination of trabecular plate separation showed that the space between the trabecular plate and trabecular bone was narrow in the Ju region. These results indicate that trabecular density in the zygomatic bone of edentulous maxillae was higher in the Ju region than in the other regions. In the midpoint and Zm regions, thinner and more separated trabeculae resulted in lower bone volume density.

Discussion

Recently, the development of micro-CT technology has allowed precise determination of the internal structure of bone. This method has been shown to be superior to conventional techniques in terms of factors that influence tissue and time and is very useful for observing the 3-dimensional internal structure of bone.[10-12] In the present study, zygomatic bones were nondestructively observed using micro-CT, in a short period of time.

Reports suggest that bone formation decreases when force applied to bone as part of normal function is weakened[13,14] and that trabecular morphology changes from a plate-like to a rod-like structure when mechanical load is decreased.[15-17] Results of the present comparison of the internal structures of zygomatic bones from edentulous maxillae indicate that the trabecular structure of the Ju region is plate-like in edentulous zygomatic bone. In contrast, trabeculae in other regions have a rod-like structure. Additionally, results of the present morphometric analysis suggest that trabecular density of edentulous zygomatic bone is higher in the Ju region than in other regions and that the trabecular structure of the Ju region consists of a plate-like structure. These findings suggest that the stress caused by muscles is concentrated in the Ju region of edentulous zygomatic bone, because of the adherence of the masseter muscles and fascia temporalis to zygomatic bone.

It was recently reported that osteocytes in the bone matrix act as pressure sensors and that there is a pressure sensory network among osteocytes, osteoblasts, and osteoclasts, although the detailed mechanism has not yet been elucidated.[18,19] The present differences in trabecular structure in edentulous zygomatic bone suggest that the stress caused by associated muscles prevents generation of osteocytes and increases activation of osteoblasts in zygomatic bone of edentulous maxillae.

Recently, Brånemark introduced an alternative method of securing posterior maxillary implant anchorage using a longer titanium implant placed through the palatal aspect of the second premolar region transantrally into the zygomatic bone.[20] Using this implant, autologous bone grafting can be avoided and the treatment period shortened, and existing bone can be used for fixture anchorage. When the zygomatic fixture is placed, the end of the fixture is installed within the 90° angle between the frontal and temporal processes of the zygomatic bone. The present findings indicate that the trabecular bone at the end of the zygomatic fixture is thicker and wider than in other regions. We conclude that this thicken-

Table 1. RESULTS OF MORPHOMETRIC ANALYSIS FOR EDENTULOUS ZYGOMATIC BONE

Reference Point	Bone Volume Density (%)	Trabecular Plate Thickness (mm)	Trabecular Plate Number (No./mm)	Trabecular Plate Separation (mm)
Jugale	23.2 ± 4.3] *	0.16 ± 0.05	1.53 ± 0.48	0.56 ± 0.20
Middle point	19.9 ± 5.4]	0.15 ± 0.05	1.38 ± 0.33	0.62 ± 0.28
Zygomaxillare	20.5 ± 6.5	0.15 ± 0.06	1.49 ± 0.40	0.58 ± 0.20

*$P < .05$, Ju versus middle point.
Values given as mean ± SD.

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ing promotes initial fixation and that when the trabeculae are able to support occlusal force after achievement of osseointegration, this thickening greatly aids in support of the fixture.

Micro-CT provides objective and detailed quantitative data about bone structure. Use of this tool can greatly enhance understanding of zygomatic fixture biomechanics. Further large-scale studies are needed to clarify microstructural variation and its impact on the mechanics of implant-bone union.

Acknowledgment

The authors thank T. Hara for use of the micro-CT system and technical advice.

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