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Comparison of mandibular trabecular bone structure and composition between dentulous and edentulous human mandibles

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Abstract

Autogenous bone grafts from various sites. Among them, as mandibles show limited structural changes with aging,they are the most effective type of bone graft for bone augmentation. However, the structure of the mandible is affected by the loss of teeth. In this study, we compared the trabecular bones of the mandibles of dentulous and edentulous Japanese cadavers by using X-ray micro-computed tomography. The mandibular symphysisand ramus were harvested from 12 dentulous and 12 edentulous cadavers, and the trabecular structures, bone mineral density (BMD), and bone volume/total volume (BV/TV) were evaluated. BV/TV was significantly higher in the symphysis than in the ramus. The BV/TV of the symphysis and ramus tended to be higher in dentulous cadavers than in edentulous cadavers. However, no significant differences were detected between the two groups. The BMD of the symphysis was significantly greater in dentulous cadavers than in edentulous cadavers. However, no significant difference was observed in the BMD of ramus between the two groups. The trabecular bone in edentulous mandibles showed thin and rod-type three-dimensional structure, while the dentulous mandibles showed thick and plate-type trabecular bones. These results indicate that BV and structure of trabecular bone in the symphysisare strongly associated with the physical stress caused by biting forces.

Keywords: micro-computed tomography (micro-CT), trabecular structure, mandibular symphysis, mandibular ramus, BMD, BV/TV

Introduction

Autogenous bone graftshave been in use for a long time in the regeneration of bone defects.[1–3] In the dental field, the practice of harvesting bone from various body parts using several techniques is common fordental implant treatment.[4–6]In addition, various artificial bone biomaterials and growth factors have been developed, but autogenous bone is still used as the gold standard.[7–10]

A mixture of cortical and trabecular bone is more useful for bone augmentation than only cortical bone.[11–13] However, bone quality might change with aging and/or diseases.[14–16]Kamal et al.[17] analyzed the three-dimensional structure of trabecular bones in the mandible, tibia, and ileus and concluded that the trabecular bone of the mandible was the most stable bone structure with no relation with aging.[17]

Mandibular symphysis and ramus are often harvested for bone grafting procedures.[18]The bone of mandibular ramus is more stable than that of symphysis and hence, the mandibular ramus is more effective for bone augmentation than the symphysis.[4]

Aging leads to limited structural changes inthe mandible;however, the reduction in physical stress such as that occurs due to tooth loss affects the mandibular structure considerably.[19–21]The flattening of the articular surface of the mandibular condyle and loss of the alveolar part of the mandible become obvious with tooth loss. In general, the structure of trabecular bones changes from plate-type to rod-type with aging.[22–24]In the case of the mandibular condyle, changes from plate-type to rod-type occur after the loss of teeth.[25] However, few reports have analyzed the structural differences among different parts of the mand.ible. In this study, we compared the structure and quality of the trabecular bone in the mandibular ramus and symphysis between dentulous and edentulous Japanese cadavers using X-ray micro-computed tomography (Micro-CT).

Materials and methods

Selection of bone specimens

This study comprised 24 Japanese cadavers (12 dentulous and 12 edentulous;age, 62-82 years, mean age, 76.5 years) with no history of diseases related to bones. Dentulous cadavers were seven male and five female, and the average age was 73.8 years. Edentulous cadavers were five male and seven female, and the average age was 89.3 years. All dentulous cadavers exhibited more than 20 teeth in their jaws.All cadavers were donated to the Showa University School of Dentistry for the purpose of human anatomical education and research. The study protocol was approved by the Institutional Committee of Showa University, Tokyo, Japan.

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Bone biopsy preparation

Bone samples were harvested using a surgical micromotor with an 8-mm inner diameter trephine bur (ACE Surgical Supply Co., MA, USA) rotating at 15,000 rpm with continuous running sterile saline irrigation. The harvest sites were the mandibular symphysis (chin) and ramus. Approximately 5–15 mm bone was harvested from the inferior margin of the mandible for samples from the mandibular symphysis region(Figure 1). Specimens from the mandibular ramus were harvested from the area between the anterior borderand the retromolar region. After removal, the specimens were fixed in 4% paraformaldehyde in phosphate buffered saline until the next experiment.

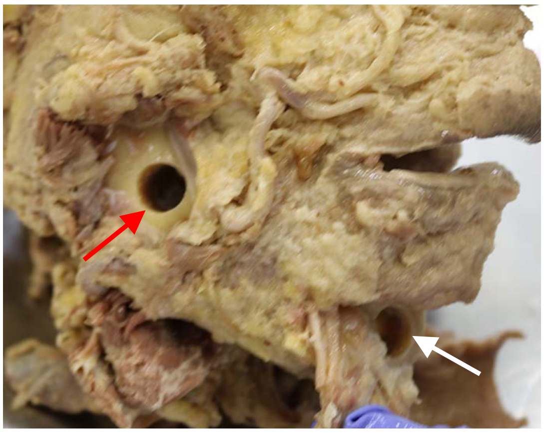

Figure 1 Technical findings of bone harvesting. (A) Mandibular symphysis area is center of the mandible, approximately 5-15 mm from the inferior margin (white arrow). Ramus area is the anterior margin to the buccal retromolar region (red arrow).

Micro-CT analysis to measure bone volume fraction and bone mineral density

Micro-CT imagesof the bone samples were obtained using the Micro Focus X-ray System SMX90–CT (Shimazu Co., Kyoto, Japan). The imaging parameters were as follows: 90 kV; 108 µA; voxel resolution, 45 µm; and 1,200 steps. The imaging data were then reconstructed, and the final 3D data comprised a 100 × 100 mm area at a resolution of 45 µm/pixel. The 3D structural analysis was performed using TRI-3D bone morphometric software (TRI-3D BONE; Ratoc Co., Tokyo, Japan). A grayscale threshold that provided morphology closest to the actual samples and the least noise was employed to extract the trabecular structures and bone volume.

The same value was used in all subsequent analyses. Quantitative measurements of cortical and cancellous bone were performed on sample cores (diameter, 8 mm) to a depth of 10 mm with the distal cortical bone considered as the base level. To distinguishbetween cortical and cancellous bone, dividing lines were introduced every 5–10 slices for all 514 slices, and a series of 3D slice surfaces were formed through a complementary calculation. Subsequently, bone mineral density (BMD, mg/cm^3), cancellous bone volume (BV, mm^3), and percentage of bone volume fraction (BV/total volume (TV), %) were calculated. BMD is defined as the volumetric density of calcium hydroxyapatite (in mg/cm^3). It is calibrated with the aid of phantoms having known BMDs.

Statistical processing

Student's t-test was used to compare the micro-CT and histomorphometrical analysis data of the four groups (dentulous symphysis, dentulous ramus, edentulous symphysis and edentulous ramus groups). All analyses were performed using a statistical software (SPSS version 21; IBM, Armonk, NY, USA). The level of significance was 5% ($p < 0.05$).

Results

BV/TV measurements

The data obtained from micro-CT of the specimens are presented in Figure 2 and Table 1. BV/TV was significantly higher in the symphysis than in the ramus. The BV/TV of the symphysis and ramus also tended to be higher in the dentulous group than in the edentulous group. However, no significant differences were detected between the two groups.

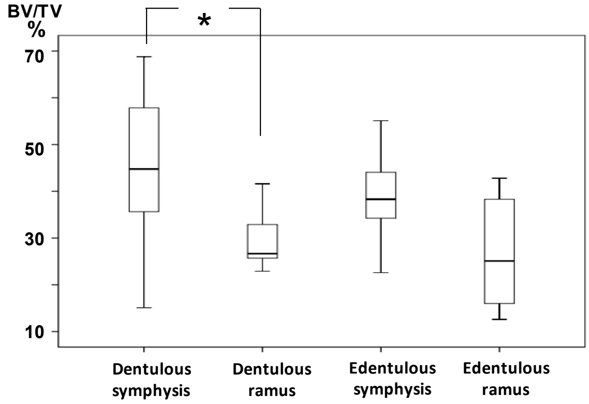

Figure 2 Micro-CT analysis of bone volume fraction in mandibular symphysis and ramus. BV/TV value of dentulous symphysis is significantly greater than dentulous ramus (*: p<0.05).

BMD measurements of cancellous bone

The data pertaining to the BMD of cancellous bone are presented in Figure 3 and Table 1. In the dentulous group, the BMD of the symphysis was significantly higher than that of the ramus. In the edentulous group, the BMD of the symphysis tended to be higher than that of the ramus. However, no significant differences were detected between the two regions. The BMD of the symphysis was significantly higher in the dentulous group than in the edentulous group.

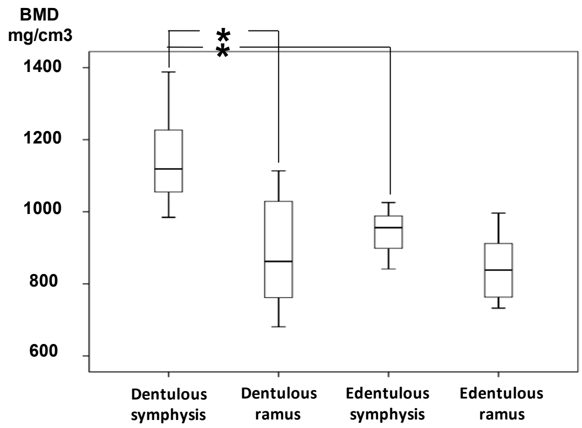

Figure 3 Micro-CT analysis of bone mineral density in mandibular symphysis and ramus. BMD value of dentulous symphysis is significantly greater than dentulous ramus and edentulous symphysis (*: p<0.05).

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Table 1 Comparison of BMD and BV/TV in four sites.

	Bone microstructures [mg/cm³]					BMD
	(N)	Parameters	BV[mm³]	TV[mm³]	BV/TV[%]	[mg/cm³]
Dentulous symphysis	6	Average	161.8	424.3	40.5	1140.8
		SD	188.3	515.9	17.6	139.1
Dentulous ramus	6	Average	104.4	330.8	31.1	906.6
		SD	74.1	183.7	7.5	150.4
Edentulous symphysis	6	Average	73.4	193.6	38.8	967.2
		SD	23.4	58.5	8.8	57.2
Edentulous ramus	6	Average	68.6	252.2	27.3	924.3
		SD	45.8	124.7	12.9	76.3

Morphological evaluation of the 3D structural images

The 3D analysis clearly showed the well-developed trabecular bones in dentulous symphysis and ramus (Figure 4A & 4B). Edentulous symphysis and ramus showed less developed trabecular bones and expansion of spaces between trabecular bones (Figure 4C & 4D), which is identical to the BV/TV results.

Observation of the trabecular bone under higher magnification showed that most of the trabecular bones of dentulous symphysis and ramus consisted of plate-type bones (Figure 4E & 4F), while the trabecular bones of edentulous symphysis and ramus showed rod-type structures (Figure 4G & 4H).

Discussion

Autogenous bone grafts have a place in the 90-year history of successful bone regeneration in the cranio-maxillofacial region.[26]Since the development of dental implant treatments, four donor sites (mandibular symphysis, mandibular ramus, ilium, and tibia) are commonly harvested for maxillofacial surgery and dental implant treatments.[26–29]

As the reconstructed bone requires sufficient strength to withstand occlusal forces and sufficient volume for the retention of dentures and implants, adequate intensity and density are necessary for harvesting bones. Kamal et al. analyzed the three-dimensional structure of trabecular bones in the mandible, tibia, and ileus and concluded that the trabecular bones of the mandible were the most stable structures with no relation to aging.[17] However, the structure of the mandible changes significantly with tooth loss.[19–21]Therefore, we analyzed the trabecular structure of the mandibular symphysis and ramus of dentulous and edentulous cadavers to clarify the effect of physical stress exerted by mastication.

We found a significant difference in BV/TV only between the symphysis and ramus of dentulous cadavers. No significant difference in BV/TV was detected between the two parts of edentulous cadavers.

In the case of BMD, significant differences were detected between dentulous symphysis and dentulous ramus, and between dentulous and edentulous symphysis. No significant difference in BMD was detected between dentulous and edentulous ramus.

The symphysis region has to withstand occlusal stresses every day,[30]and this maintains the activity of this region in elderly people. These results strongly suggest that BV/TV and BMD of the symphysis are regulated by the physical stresses exerted by mastication.

Although the average ages of dentulous and edentulous cadavers analyzed in this study were different, there was no significant difference in BV/TV and BMD of the mandibular ramus between dentulous and edentulous mandibles, which suggests that physical stress and difference in age might not fundamentally affect the structure and quality of trabecular bone in the mandibular ramus. However, we observed a tendency for change in the form of trabecular bones from plate-type to rod-type with the loss of teeth. Further studies are necessary to clarify the effects of physical stress on the structure and quality of trabecular bones in the mandibular ramus.

Our previous study indicated a difference in hematopoietic development of the bone marrow between intramembranous and endochondral osteogenesis.[31]In intramembranous bones, erythropoiesis occurs first while granulopoiesis is the initial step in endochondral bones. Most long bones in the body are formed by endochondralosteogenesis. These bones show osteoporosis, and the bone marrow of these bones become filled with adipose tissue.[32]

In the mandibular bone marrow, the conversion from hematopoietic to fatty marrow occurs first in the symphysis followed by the body, ramus, and condyle.[33] Bone marrow-derived mesenchymal stem cells from neural crest-derived bones, such as the mandible and maxilla, have increased potential to induce osteogenesis than mesoderm-derived appendicular bones.[34,35]These results also support the stability of trabecular bones in the mandible with respect to age and the difference in bone marrow cells surrounding the trabecular bones strongly affecting bone quality.

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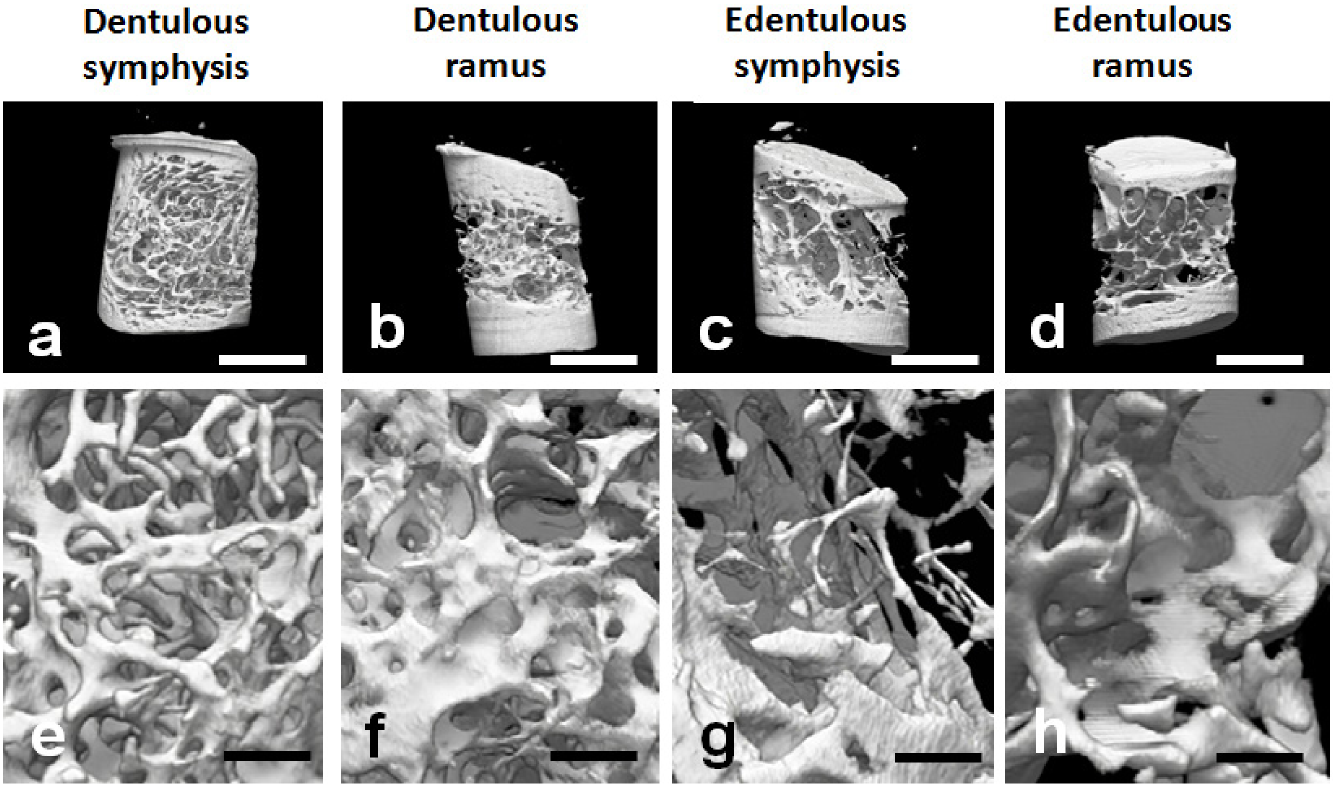

Figure 4 Three-dimensional morphological observations of the bone biopsy samples. Dentulous symphysis (a, e), dentulous ramus (b, f), edentulous symphysis (c, g) and edentulous ramus (d, h). Trabecular bone was tended to more develop in dentulous symphysis (a) and ramus (b) than in edentulous symphysis (c) and ramus (d). Higher magnification of trabecular bones showed plate-type structures in dentulous symphysis (e) and ramus (f), and edentulous ramus (h). Edentulous symphysis composed of rod-type trabecular bones (g). Bars = 3500 μm (a-d), and 500 μm (e-h).

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