Variations in trabecular bone ratio according to age, sex, and mechanical stimulus using micro-CT in Koreans

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본 논문이 나오기까지 부족한 저를 이끌어 주시고 많은 가르침과 격려를 통해 지도 편달해 주신 정문규 지도교수님께 깊은 존경과 감사를 드립니다. 논문의 작성과 심사에 아낌없이 조언과 도움을 주신 문홍석 교수님, 심준성 교수님, 김희진 교수님, 허경석 교수님께도 깊은 감사를 드립니다.

연구 기간 동안 아낌없이 자문을 해주신 김성태 교수, 실험하는데 많은 도움을 주신 허경석 교수팀 해부학 연구진, 바쁜 임상 과정중에서도 논문을 쓸수 있게 정신적, 시간적으로 도움을 준 고운미소 원장들과 스텝 선생님들께 다시 한번 감사의 마음을 드립니다.

제가 이 세상에서 가장 존경하는 아버님, 어머님. 늘 사랑으로 보살펴주시는 장인, 장모님. 저의 인생 동반자로서 항상 믿고 사랑해주는 아내 서명진, 지친 삶속에서도 활력소가 되어준 두 아들 지호, 민서에게 기쁨과 감사의 마음을 전합니다.

2009년 6월

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Abstract

Variations in trabecular bone ratio according to age, sex, and mechanical stimulus using micro-CT in Koreans

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(Directed by Professor Moon-Kyu Chung, DDS., PhD)

A decrease in bone mineral density (BMD) is analogous to a reduction in the cortical bone or the trabecular portion of cancellous bone, which play important roles in maintaining the general structure of bone. Decreases in BMD are related to increasing age, sex, and tooth loss, but most of the related studies employed conventional radiographic analysis, and data from the Korean population are rare. The aim of this study was to elucidate the trabecular pattern of the jaw bone using micro computed tomography (micro-CT). Seventy-seven (39 mandibles, 38 maxillae) specimens were prepared from fully and partially dentate jaws. Specimens were scanned with micro-CT and reconstructed three dimensionally. Sections were made parallel to the axis of each tooth. The trabecular bone ratio (TBR) was measured, with the data being statistically using one-way ANOVA (α=.05). The TBR differed significantly between dentate and edentulous mandibles in the molar region and between dentate and edentulous maxillae in the first molar region. The TBR values of edentulous maxillae and mandibles were higher in males than in females. The TBR decreased monotonically with increasing age in dentate but not edentulous mandibles. From these results it can be concluded that the TBR varies significantly according to the presence of teeth, sex, and age in specific areas.

Keywords: mandible, maxilla, dental implant, trabecular bone, dentate, edentate, sex, age, micro-CT

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I. INTRODUCTION

Bone is composed of compact bone and cancellous bone. The cancellous portion is important for nutritional support and mechanical support in osteogenesis, and it comprises trabeculae and medullary cavities. Trabeculae are latticelike bony columns that are important for mechanical support, and medullary cavities play important roles in hematopoiesis and in the coordination of calcium and phosphate. Osteoblasts and osteoprogenitor cells on the endosteum participate in osteogenesis. The composition of cancellous bone differs between individuals, with the osteogenic potential and mechanical support from cancellous bone varying according to the physical constitution.

The remodeling of alveolar cortical and cancellous portions of the bone continues with increasing age (Ulm et al., 1999). For example, in the edentulous mandible, the cortical portion thickens, and the cancellous portion subsequently thins (Ulm et al., 1994). This reduction of cancellous portion may be regarded as a physiological aging process that starts in the 3rd or 4th decade of life.

This reduction is generally more marked in females than in males (von Wowern and Stoltze, 1978; Gulsahi et al., 2008), and notably is three times higher in postmenopausal women than in men (Gulsahi et al., 2008). Estrogen hormone plays an important role in the coordination of calcium and phosphate, and this is important for skeletal growth and maintenance. Decreased secretion of estrogen hormone is considered to effect a rapid reduction of bone mass (Glowacki, 2007).

The mineral density of cancellous bone varies according to the presence of teeth. Tooth loss leads to irreversible vertical resorption of the alveolar bone (Ulm et al., 1997, 1999). Following the loss of mandibular teeth, the basal portion of trabecular bone is stronger and denser configuration than the cranial portion (Ulm et al., 1997). That report mentioned that cranial portion may demonstrate the reduction of the functional side after tooth loss.

The maxilla also undergoes many changes after tooth loss. Glowacki (2007) reported that bone reductions following tooth loss are more rapid and extreme in the maxilla than in the mandible. These differences influence the volumes of cortical and cancellous bone as well as the reduction of medullary cavity. Thus, morphological differences between the maxilla and mandible are considered useful clinical reference data. The literature contains more studies related to the premolar region than to the anterior teeth region. Most previous studies have investigated two regions of jaws (anterior and posterior), but more specific data would be helpful for clinicians.

The results from various basic studies that have investigated the edentulous area and surrounding anatomic structures have improved clinical outcomes of implant dentistry. The anatomic structures that are important during implant surgery have been investigated (Dharmar, 1997; Kieser et al., 2004; Neiva et al., 2004; Kieser et al., 2005; Hu et al., 2007; de Oliveira et al., 2008; Nimigean et al., 2008; Hur et al., 2009).

Especially, the bone quality of the edentulous area is considered to be one of the most important factors determining the clinical outcome of dental implant. The bone quality has been studied using CT, MRI, radiography, and panoramic viewing (Ulm et al., 1994; Lindh et al., 1996a, 1996b; Taguchi et al., 1997a, 1997b; Fanuscu and Chang, 2004; Turkyilmaz et al., 2007; Gulsahi et al., 2008). These methods seem appropriate for evaluating conditions of the edentulous area prior to implant surgery as well as for providing basic anatomical information. Micro-computed tomography (micro-CT) can also be an appropriate tool with many advantages for detailed evaluations of the bone microstructure (Choel et al., 2004; Fanuscu and Chang, 2004; Moon et al., 2004). This is a noninvasive method allowing the acquisition of information on the degree of mineralization of trabecular bone as distinct from the cortex (Lindh et al., 1996a), and it has been used to determine the role of the trabecular architecture on the mechanical properties of bone by assessing specific parameters in three dimensions (Choel et al., 2004). Micro-CT might also provide useful information to clinicians determining the treatment planning of implant therapy.

Therefore, the aim of this study was to determine the influence of the presence of teeth, sex, and age on the bone quality in different tooth regions of the jawbone using micro-CT.

Ⅱ. MATERIALS AND METHODS

1. Materials

Seventy-seven (39 mandibles, 38 maxillae) specimens were prepared from fully and partially dentate jaws. The mandible specimens were from 18 males (mean age 67.4 years, range 54 – 95 years) and 21 females (mean age 76.8 years, range 48 – 95 years), and the maxilla specimens were from 22 males (mean age 66.0 years, range 45 – 89 years) and 16 females (mean age 70.9 years, range 42 – 95 years). Specimens with visible surface damage were not included in this study. The study protocol was approved by the Ethics Committee of Yonsei Medical Center, Korea. All specimens were cleaned of all soft tissue and fixed in 10% neutralized buffered formalin.

2. Methods

The sequence of procedures used to determine the trabecular bone ratio (TBR) in the jawbone is shown in Figure 1. The specimens were first scanned by micro-CT (Skyscan 1076, Skyscan Co., Antwerp, Belgium) comprising an X-ray microscope with a high-definition X-ray microfocus tube with a focal spot diameter of 10 μm, and a 1.0-mm-thick aluminum filter to remove noise during X-ray scanning, a precision-controlled specimen holder, a two-dimensional X-ray CCD camera connected to a frame grabber, and a workstation (with dual Xeon 3.0G processors) with tomographic reconstruction software. The specimen was placed on the holder between the X-ray source and the CCD camera and was rotated around the vertical axis at intervals of 0.9° for 180° whilst being kept within the field of view, producing 200 projections. The beam was projected onto a phosphorus screen to convert the X-rays into visible light that could be detected by a CCD camera. The data were then digitized by the frame grabber and transmitted to the computer hosting the topographic reconstruction software. The serial two-dimensional (2D) images obtained by micro-CT were cross-sectional images comprising 1968X1968 pixels. A three-dimensional (3D) structural image with voxels of size 35X35X35 mm was reconstructed from 2D images in which each pixel represented an area of 35X35 mm. After reconstructing the 3D image of the jawbone, the specimen was sectioned perpendicular to the buccal and lingual plates at all tooth regions in order to measure the TBR (Fig. 2). On the sectional images, the cortical portion consisting of an extra layer of bone was dissociated with the cancellous portion of the bone using image processing software (Adobe Photoshop CS3, ver. 10.0, Adobe Co., USA) (Fig. 3). The ratio occupied by trabecular bone in the dissociated cancellous portion was then measured automatically with image analysis software (Image-Pro®Plus, ver. 4.0, Media Cybernetics Co., USA). These results were statistically analyzed using standard spreadsheet software (Microsoft® Office Excel® 2007, ver. 12.0, Microsoft co., USA) in the following separate parts: (1) mandible (subparts: dentate and edentulous, males and females, and different ages), (2) mandible (subparts: dentate and edentulous, males and females, and different ages), and (3) comparison between mandible and maxilla (subparts: dentate and edentulous).

The mean and standard deviation were calculated for each parameter, and a t-test was used to examine whether value differences between parameters, such as the presence of teeth and sex, were significant (at 95% confidence interval, $p<0.05$). Analysis of variance (ANOVA) was also used to determine whether differences between regions were statistically significant (at 95% confidence interval, $p<0.05$).

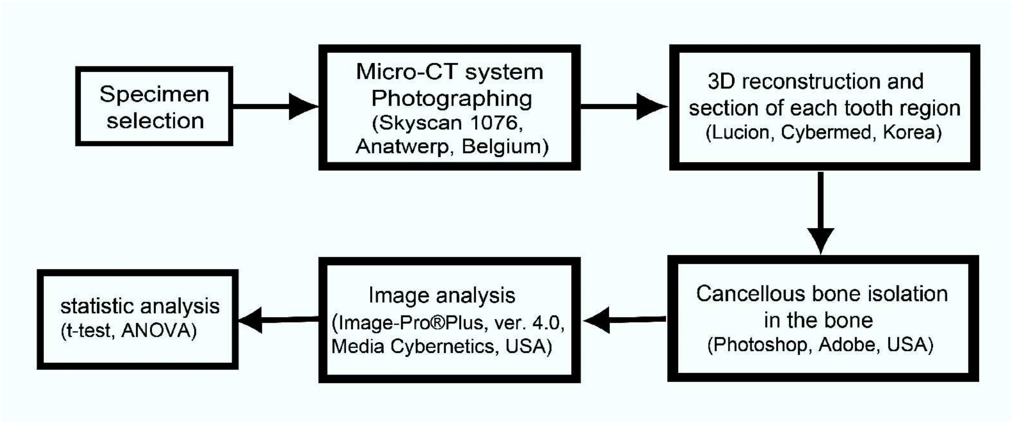
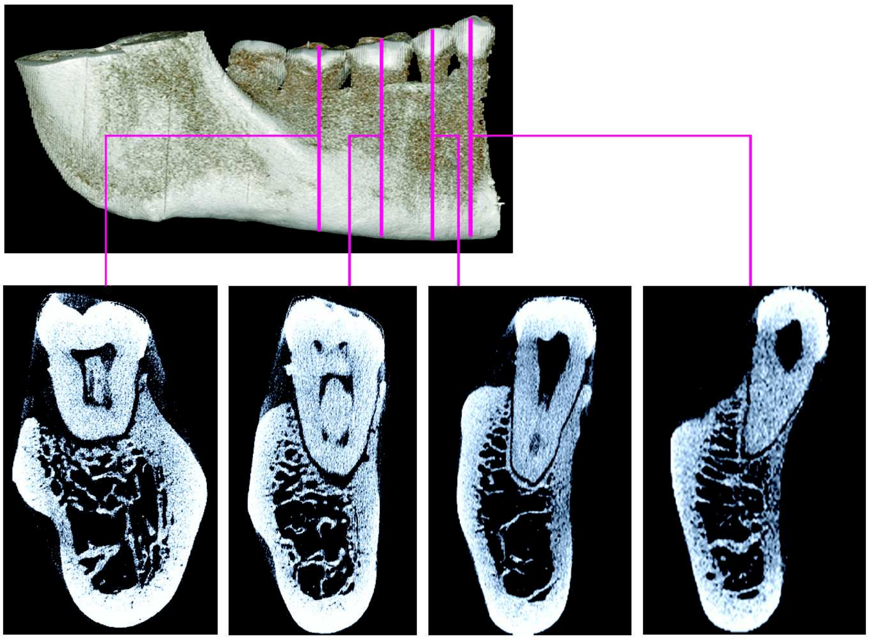


Fig. 1. Schematic of the procedures used to determine the trabecular bone ratio



(a) (b) (c) (d)

Fig.2. After reconstructing the 3D image of the mandible, the specimens were sectioned perpendicular to buccal and lingual plates in all tooth regions in order to measure the trabecular bone ratio. (a) Second molar, (b) first premolar, (c) second premolar, and (d) first premolar

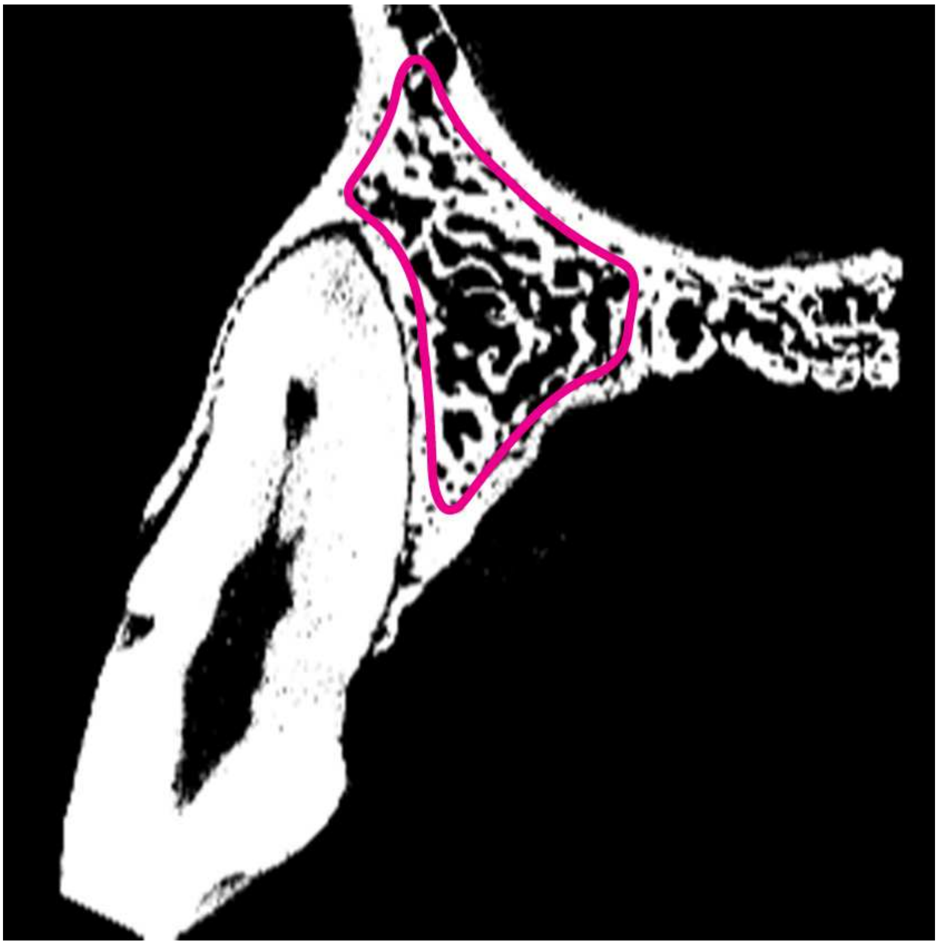


Fig. 3. On the sectional images, the outer cortical plate was dissociated from the cancellous portion of the bone.

Ⅲ. RESULTS

The calculated trabecular bone ratio (TBR) values according to the presence of teeth, sex, and age are presented in Tables 1 - 8.

1. Mandible

ⅰ) Comparison of TBR between dentate and edentulous regions

The TBR of mandible in all tooth regions had statistically significant difference in both dentate and edentulous groups ($p<0.05$). The TBR was significantly higher in the dentate than in the edentulous mandible in the first and second molar regions ($p<0.05$) but not in other regions ($p>0.05$), and was highest in the central incisor region (Table 1). In the dentate mandible, the TBR reduced gradually from the incisor region to the premolar region, and then increased gradually towards the molar region (Fig. 4). In the edentulous mandible, the TBR reduced gradually from the central incisor region to the molar region.

ⅱ) Comparison of TBR between sexes

In dentate mandibles, TBR was greater in males than in females, but it is not differ significantly between males and females (Table 2). In all tooth regions of edentulous mandibles it was lower in females than in males. The TBR of the central incisor, first molar, and second molar regions was a statistically significant difference between males and females ($p<0.05$).

ⅲ) Comparison of TBR between age categories

Comparative analysis of the age groups revealed that it was possible to divide them into three distinct groups. The TBR reduced monotonically in the incisor and premolar regions of dentate mandibles, but in the molar region the variation was nonmonotonic (Table 3). However, the differences were not statistically significant ($p>0.05$). Edentulous mandibles generally showed nonmonotonic variations in the TBR, but the differences were only statistically significant in the second molar region ($p<0.05$), where it reduced from 59 to 70 years (Table 4).

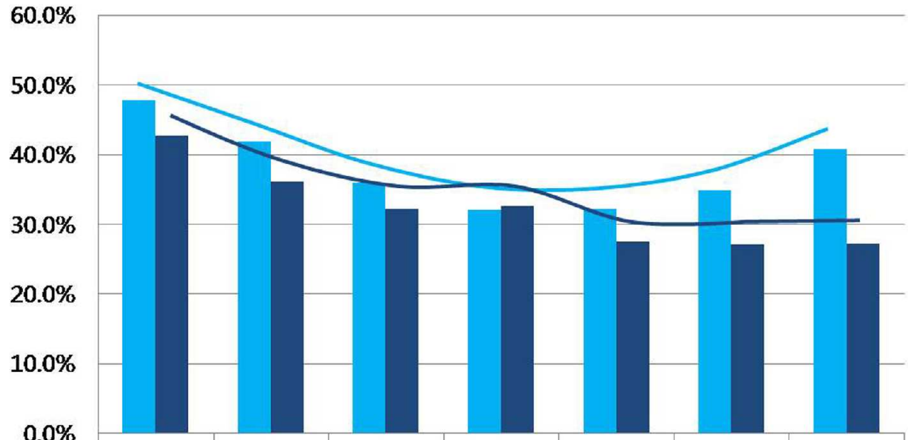
Table 1. Comparison of TBR between dentate and edentulous mandibles

Region	Dentate[A]	Edentulous[B]	Comparison Avs B
	Mean ± SD (*N*)	Mean ± SD (*N*)	*P*
Central incisor	47.8±13.9% (18)	42.7±11.4% (21)	0.217
Lateral incisor	41.9±12.5% (22)	36.0±8.3% (16)	0.112
Canine	35.9±11.3% (27)	32.1±6.6% (14)	0.258
First premolar	32.0±9.5% (23)	32.6±8.0% (19)	0.832
Second premolar	32.2±10.1% (19)	27.5±9.9% (23)	0.134
First molar	34.8±9.7% (14)	27.0±10.6% (24)	0.029†
Second molar	40.8±8.9% (13)	27.2±9.8% (26)	0.000†
P	0.000	0.000	

SD: standard deviation, N: number of specimens

TBR: trabecular bone ratio

† : statistically significant in the mean TBR between dentate and edentulous ($p<0.05$)



	Central incisor	Lateral incisor	Canine	First premolar	Second premolar	First molar	Second molar
Dentate	47.80%	41.90%	35.90%	32.00%	32.20%	34.80%	40.80%
edentulous	42.70%	36.00%	32.10%	32.60%	27.50%	27.00%	27.20%

Fig. 4. The graph that compare trabecular bone ratio (TBR) between dentate and edentulous mandibles. The line indicate the increase or decrease of TBR in dentate and edentulous mandible.

Table 2. Comparison of TBR in dentate and edentulous mandibles between males and females

Region	Dentate			Edentulous		
	Males [Mean ± SD(*N*)]	Females [Mean ± SD(N)]	*P*	Males [Mean ± SD(N)]	Females [Mean ± SD(N)]	*P*
Central incisor	51.3±10.7% (10)	43.3±16.8% (8)	0.231	47.7±12.3% (10)	38.1±8.5% (11)	0.049†
Lateral incisor	46.0±12.9% (13)	36.0±9.7% (9)	0.062	39.5±9.3% (7)	33.4±6.6% (9)	0.145
Canine	37.1±11.1% (17)	33.7±11.9% (10)	0.460	33.2±4.4% (5)	31.4±7.8% (9)	0.646
First premolar	34.1±9.5% (13)	29.2±9.4% (10)	0.233	33.8±9.1% (9)	31.5±7.3% (10)	0.545
Second premolar	34.7±10.9% (11)	28.8±8.3% (8)	0.219	31.5±11.3% (11)	23.7±6.8% (12)	0.056
First molar	35.9±12.7% (8)	33.3±4.0% (6)	0.638	33.3±11.1% (11)	21.6±6.5% (13)	0.004†
Second molar	41.5±11.9% (7)	40.0±4.5% (6)	0.781	32.7±9.8% (13)	21.6±6.2% (13)	0.002†

SD: standard deviation, N: number of specimens

TBR: trabecular bone ratio

† : statistically significant in the mean TBR between male and female ($p<0.05$)

Table 3. Comparison of TBR in the dentate mandible between age categories

Region	Dentate			
	≤59 years [Mean±SD (N)]	60-69 years [Mean±SD (N)]	≥70 years [Mean±SD (N)]	*p*
Central incisor	56.8±6.5% (8)	42.2±15.7% (8)	34.0±3.4% (2)	0.026†
Lateral incisor	46.4±7.1% (9)	40.2±17.2% (9)	35.7±7.1% (4)	0.334
Canine	41.9±6.5% (9)	34.6±13.7% (12)	28.1±3.9% (5)	0.072
First premolar	35.3±7.6% (9)	31.7±11.9% (9)	26.6±6.5% (5)	0.271
Second premolar	35.3±11.1% (9)	30.8±9.9% (6)	27.2±7.1% (4)	0.401
First molar	31.7±6.7% (7)	39.1±12.3% (6)	30.4% (1)	0.378
Second molar	40.5±10.0% (7)	41.1±8.5% (6)	-	0.993

SD: standard deviation, N: number of specimens

TBR: trabecular bone ratio

† : statistically significant in the mean TBR among age ($p<0.05$)

Table 4. Comparison of TBR in the edentulous mandible between age categories

Region	Edentulous			
	≤59 years [Mean±SD (N)]	60-69 years [Mean±SD (N)]	≥70 years [Mean±SD (N)]	*p*
Central incisor	59.8% (1)	45.5±14.5% (8)	39.4±7.6% (12)	0.121
Lateral incisor	46.1±4.5% (2)	34.5±7.8% (4)	34.6±8.1% (10)	0.19
Canine	34.0±4.4% (2)	31.5±5.6% (3)	31.8±7.8% (9)	0.636
First premolar	28.8±11.3% (2)	35.7±9.1% (7)	31.2±6.9% (10)	0.45
Second premolar	28.0±13.9% (2)	31.8±12.0% (9)	24.1±6.6% (12)	0.215.
First molar	28.6±8.5% (3)	35.4±13.1% (7)	22.4±6.7% (14)	0.019†
Second molar	36.3±9.5% (3)	31.8±11.9% (8)	22.9±6.2% (15)	0.02†

SD: standard deviation, N: number of specimens

TBR: trabecular bone ratio

† : statistically significant in the mean TBR among age ($p<0.05$)

2. Maxilla

ⅰ) Comparison of TBR between dentate and edentulous regions

The TBR of maxillae in all tooth regions had statistically significant difference in dentate group ($p<0.05$) but edentulous group is not statistically significant difference ($p<0.05$)(Table5). The TBR differed significantly between dentate and edentulous first molar regions ($p<0.05$) but not in the other regions ($p>0.05$).

Comparing data between dentate and edentulous regions revealed a contrast between anterior teeth regions (incisor and canine regions) and posterior teeth regions (premolar and molar regions). The TBR was higher in the dentate than in the edentulous anterior teeth region, but it was higher in the edentulous posterior teeth region (Fig. 5).

ii) Comparison of TBR between sexes

In dentate maxillae, the TBR in lateral incisor, canine, second premolar and first molar region was higher in males than in females, but only canine region shown statistically significant difference ($p<0.05$)(Table 6). In edentulous maxillae, the TBR did not differ significantly between male and females in any tooth region except for lateral incisor($p>0.05$).

iii) Comparison of TBR between age categories

Comparative analysis of the age groups revealed that it was possible to divide them into three groups. The TBR reduced monotonically in the incisor region of the dentate maxilla, but in the canine, premolar, and molar regions the variation was nonmonotonic (Table 7). In addition, the variations in TBR were more consistently monotonic in dentate maxillae than in edentulous maxillae.

The TBR reduced monotonically in the molar and first premolar regions of edentulous maxillae, but in other regions the variations were nonmonotonic (Table 8). However, none of the variations in either the dentate or edentulous maxillae were statistically significant ($p>0.05$).

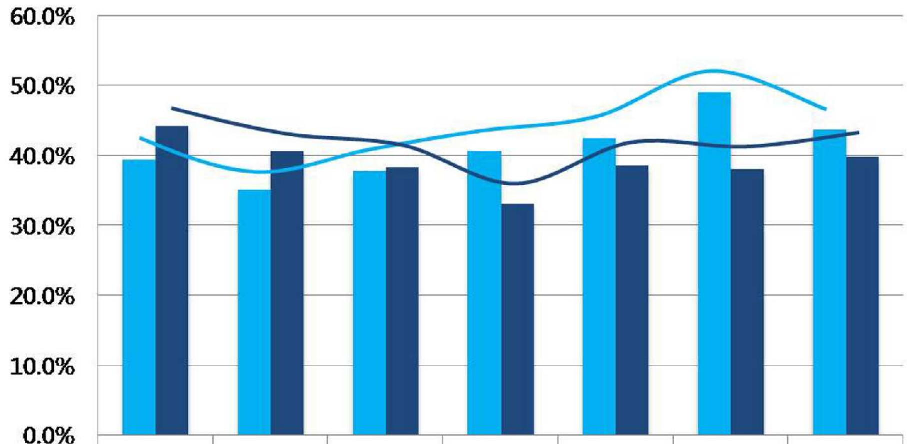
Table 5. Comparison of TBR between dentate and edentulous maxillae

Region	Dentate[A]	Edentulous[B]	Comparison A vs B
	Mean ± SD (*N*)	Mean ± SD (*N*)	*P*
Central incisor	39.4±10.8%(26)	44.2±11.4%(8)	0.286
Lateral incisor	35.0±10.6%(28)	40.6±8.2%(7)	0.199
Canine	37.7±10.2%(32)	38.3±5.0%(3)	0.9130
First premolar	40.6±12.3%(24)	33.0±13.4%(12)	0.095
Second premolar	42.5±11.8%(20)	38.5±10.5%(12)	0.346
First molar	49.0±12.4%(16)	38.0±7.7%(13)	0.010†
Second molar	43.6±12.9%(18)	39.8±9.1%(12)	0.386
P	0.0046	0.3683	

SD: standard deviation, N: number of specimens

TBR: trabecular bone ratio

† : statistically significant in the mean TBR between dentate and edentulous ($p<0.05$)



	Central incisor	Lateral incisor	Canine	First premolar	Second premolar	First molar	Second molar
Dentate	39.40%	35.00%	37.70%	40.60%	42.50%	49.00%	43.60%
edentulous	44.20%	40.60%	38.30%	33.00%	38.50%	38.00%	39.80%

Fig. 5. The graph that compare trabecular bone ratio (TBR) between dentate and edentulous maxillae. The line indicate the increase or decrease of TBR in dentate and edentulous mandible.

Table 6. Comparison of TBR in dentate and edentulous maxillae between males and females

Region	Dentate			Edentulous		
	Males [Mean ± SD(*N*)]	Females [Mean ± SD(N)]	*P*	Males [Mean ± SD(N)]	Females [Mean ± SD(N)]	*P*
Central incisor	39.3±11.2% (16)	39.6±10.8% (10)	0.946	45.1±7.0% (2)	43.9±13.1% (6)	0.912
Lateral incisor	36.5±11.5% (16)	32.9±9.2% (12)	0.389	35.7±7.8% (3)	44.3±7.3% (4)	0.195
Canine	42.2±9.8% (17)	32.5±8.1 (15)	0.005†	41.2±0.9% (2)	32.6%(1)	0.430
First premolar	39.7±13.4% (15)	42.2±10.9% (9)	0.643	36.8±8.8% (5)	30.2±16.0% (7)	0.545
Second premolar	46.8±11.1% (10)	38.2±11.3% (10)	0.106	41.3±12.3% (7)	34.6±6.7% (5)	0.297
First molar	51.4±9.2% (9)	45.9±15.8% (7)	0.401	39.9±5.7% (9)	33.7±10.7% (4)	0.187
Second molar	40.8±9.1% (10)	47.1±16.5% (8)	0.316	42.0±7.4% (8)	35.5±11.8% (4)	0.258

SD: standard deviation, N: number of specimens

TBR: trabecular bone ratio

† : statistically significant in the mean TBR between male and female ($p<0.05$)

Table 7. Comparison of TBR in the dentate maxilla between age categories

Region	Dentate			
	~59 years [Mean±SD (N)]	60~69 years [Mean±SD (N)]	70~ years [Mean±SD (N)]	*p*
Central incisor	40.4±8.45%(9)	40.2±15.8%(7)	37.9±9.7%(10)	0.861
Lateral incisor	39.1±12.5%(12)	35.4±10.7%(6)	29.7±5.3%(10)	0.115
Canine	39.0±12.0%(12)	41.5±10.3%(7)	34.3±7.7%(13)	0.278
First premolar	38.1±15.4%(11)	44.9±7.9%(7)	40.3±10.4%(6)	0.547
Second premolar	39.1±11.8%(9)	47.8±12.4%(5)	43.2±11.5%(6)	0.425
First molar	47.7±11.1%(9)	50.4±11.4%(5)	51.1±27.5%(2)	0.913
Second molar	43.5±15.1%(10)	46.4±9.7%(5)	39.5±12.2%(3)	0.786

SD: standard deviation, N: number of specimens

TBR: trabecular bone ratio

Table 8. Comparison of TBR in the edentulous maxilla between age categories

Region	Edentulous			
	~59 years [Mean±SD (N)]	60~69 years [Mean±SD (N)]	70~ years [Mean±SD (N)]	*p*
Central incisor	37.9±3.1%(2)	50.0%(1)	45.6±13.9%(5)	0.218
Lateral incisor		44.1%(1)	40.0±9.9%(6)	0.931
Canine		41.8%(1)	36.6%±5.6%(2)	
First premolar	50.5%(1)	39.5%(1)	30.6±13.9%(10)	0.247
Second premolar	46.0±18.0(3)	46.4%(1)	34.7±5.9%(8)	0.209
First molar	41.9±6.8%(2)	41.9±0.5%(2)	36.3±7.7%(9)	0.408
Second molar	47.4±15.1%(2)	40.9%(1)	38.0±8.8%(9)	0.325

SD: standard deviation, N: number of specimens

TBR: trabecular bone ratio

3. Comparison between mandible and maxilla

In dentate, the TBR was significantly higher in the mandible than in the maxilla between central incisor and lateral incisor, but higher in the maxilla than mandible from first premolar to first molar ($p<0.05$)(Table 9).

In edentulous, the TBR was significantly higher in the maxilla than in the mandible from second premolar to second molar ($p<0.05$), but not in other regions ($p>0.05$) (Table 10).

Table 9. Comparison of TBR between the mandible and maxilla in dentate

Region	Mandible[A]	Maxilla[B]	Comparison A vs B
	Mean ± SD (*N*)	Mean ± SD (*N*)	*P*
Central incisor	47.8±13.9%(18)	39.4±10.8%(26)	0.031†
Lateral incisor	41.9±12.5%(22)	35.0±10.6%(28)	0.039†
Canine	35.9±11.3%(27)	37.7±10.2%(32)	0.521
First premolar	32.0±9.5%(23)	40.6±12.3%(24)	0.010†
Second premolar	32.2±10.1%(19)	42.5±11.8%(20)	0.006†
First molar	34.8±9.7%(14)	49.0±12.4%(16)	0.002†
Second molar	40.8±8.9%(13)	43.6±12.9%(18)	0.499

SD: standard deviation, N: number of specimens

TBR: trabecular bone ratio

† : statistically significant in the mean TBR between mandible and maxilla ($p<0.05$)

Table 10. Comparison of TBR between the mandible and maxilla in edentulous

Region	Mandible[A]	Maxilla[B]	Comparison A vs B
	Mean ± SD (*N*)	Mean ± SD (*N*)	*P*
Central incisor	42.7±11.4%(21)	44.2±11.4%(8)	0.747
Lateral incisor	36.0±8.3%(16)	40.6±8.2%(7)	0.237
Canine	32.1±6.6%(14)	38.3±5.0%(3)	0.149
First premolar	32.6±8.0%(19)	33.0±13.4%(12)	0.924
Second premolar	27.5±9.9%(23)	38.5±10.5%(12)	0.004†
First molar	27.0±10.6%(24)	38.0±7.7%(13)	0.002†
Second molar	27.2±9.8%(26)	39.8±9.1%(12)	0.001†

SD: standard deviation, N: number of specimens

TBR: trabecular bone ratio

† : statistically significant in the mean TBR between mandible and maxilla ($p<0.05$)

Ⅳ. DISCUSSION

The TBR was measured in this study to evaluate the bone mineral density (BMD). The variations in TBR were evaluated according to the presence of teeth, aging, and sex. The TBR values of cancellous bone in the posterior teeth area of the maxilla and mandible were significantly higher in dentate regions than in edentulous regions. A continuous and irreversible process of bone reduction occurs after tooth loss (Ulm et al., 1994). Trabeculae in cancellous bone also appeared to decrease after the loss of teeth in this study, which can be explained by the loss of mechanical stimuli (Lindh et al., 1996b; Nomura et al., 2007). A mechanical stimulus such as the bite force is distributed to the alveolar bone via the teeth and periodontal ligament, and the loss of such stimuli causes atrophic changes in the periodontal ligament, vascular constriction, decreased alveolar bone mass, and accelerated bone resorption (Nomura, 1982; Tanaka et al., 1998; Muramoto et al., 2000; Iwasaki-Hayashi et al., 2001; Toyooka et al., 2001). The BMD was found to decrease in cancellous bone of the atrophic mandible (Rosenquist et al., 1978). A decreased TBR in the edentulous mandible can be explained by this atrophic change of the mandible and a decrease in the mineral density of cancellous bone. However, functional stress caused by masticatory muscles also affects maintenance of the BMD in the edentulous area of the mandible. Even after the extraction of a tooth, the BMD can be maintained in the area where masticatory muscles attach in physically active individuals in whom these muscles are well developed (Klemetti et al., 1994a, 1994b). Therefore, there must be personal differences in the change in BMD after tooth loss. Opposing dentition also should be taken into consideration, since this will affect the stimulation induced by the bite force.

Sex-related BMD variations were evaluated in this study. The TBR was higher in males than in females in the central incisor and molars in edentulous mandibles, and in all areas except the lateral incisors area in edentulous maxillae. Coordination of the calcium and phosphate substances occurs in cancellous bone, and this is affected by systemic hormones. The proportions of calcium and phosphate are closely related to bone formation, and they influence the trabecular pattern directly or indirectly (Standring et al., 2005). The secreted sex-related hormones differ between males and females, which can affect the pattern of the trabecular bone and BMD (Ulm et al., 1994). Henriksson et al. (1974) found that the mean value was 8% lower in women. Most of the female cadavers in the present study were from subjects older than 50 years, which usually represents the postmenopausal period associated with a greater chance of osteoporosis causing a BMD decrease. It has been reported that the BMD tends to be lower in postmenopausal women (Lindquist et al., 1979; Solar et al., 1994). However, the BMD was found to be higher in obese women irrespective of their menopausal status. This indicates that there are factors other than osteoporosis that play important roles in BMD changes during the postmenopausal period. In the present study, a physiological sex-related decrease in BMD was found in the mandible but not in the maxilla.

Age-related BMD variations were also evaluated in this study. The TBR of dentate mandibles reduced monotonically with increasing age, while that of edentulous mandibles did not. Previous studies have shown that the BMD of the skeleton decreases beyond the age of 40 years, with the BMD at 65 years being two-thirds of that at 40 years (Gordan et al., 1985). Age-related bone loss seems to be related to decreased physical activity, lowered secretion of estrogen, diet, race, and heredity (Krolner et al., 1983). Previous studies have found that BMD was lower in older subjects both in dentate and edentulous areas (Boyde and Kingsmill, 1998). Mazes (1982) reported that the BMD of cancellous bone decreases by 6–8% every 10 years. Rosenquist et al. (1978) found a statistically significant relationship between the specific weight of the mandible and aging, with the decrease in the weight of the mandible being considered as a decrease in BMD because bone density was markedly reduced in individuals who suffered from severe mandibular atrophy. However, no relationship between BMD and increasing age in the edentulous area was found in the present study, which might be due to the atrophic changes of the mandible and the decreases in BMD occurring after extraction being relatively independent of age. Moreover, it was not known when the teeth were extracted. The atrophic change would probably be more severe and the decrease in bone density would probably be greater in the edentulous area as time passed after extraction. Therefore, the age of patient could not be directly related to a decrease in bone density.

In dentate group, the TBR in mandibular anterior region was greater than that in maxillary anterior teeth region. But, in edentulous group, there was not any statistically significant difference between mandibular anterior region and maxillary anterior region. It elucidates that more remarkable decrease of TBR occurs in mandibular anterior teeth region than maxillary anterior teeth region after loss of teeth. In posterior region, TBR of maxilla was higher than that of mandible regardeless of the presence of teeth. It means TBR doesn't decrease remarkably in mandibular posterior area as it does in mandibular anterior area after loss of teeth. Even if mandibles generally have higher mineral bone densities than maxilla, it is not because of higher bone density in cancellous bone, but more cortical bone area. Dentate group showed a regular pattern in change of TBR, but edentulous group didn't. It shows that loss of teeth affected the TBR. Therefore, a regular pattern of TBR could not be found in edentulous group.

Bone is composed of compact bone and cancellous bone. Cancellous bone contains trabeculae and medullary cavities, and its BMD was investigated previously because mechanical support and the osteogenic potential vary with the bone density (Moon et al., 2004; Neiva et al., 2004). A high BMD in cancellous bone indicates a high proportion of trabeculae providing mechanical support, whereas a low BMD indicates a high proportion of medullary cavities, which provide osteogenic potential. The mechanical support from the trabeculae of cancellous bone is important in implant dentistry, where initial stability of a dental implant is essential for a successful treatment outcome. The initial stability of an implant placed in impaired cortical bone will depends on the mineral portion of cancellous bone (Shapurian et al., 2006; Amorim et al., 2007; Turkyilmaz et al., 2007; Gulsahi et al., 2008). The osteogenic potential of cancellous bone is important in regenerative periodontal therapy and implant dentistry. Osteogenesis is the process of the formation of new bone by osteoblasts, and most regenerative periodontal therapies are based on maximizing the osteogenic potential of surrounding bone. Even when a dental implant is initially stable, a successful treatment outcome is still dependent on osteogenesis from cancellous bone (Standring et al., 2005; Amorim et al., 2007). Therefore, the mechanical support and osteogenic potential of cancellous bone are equally important in regenerative periodontal therapy and implant therapy, and these parameters can be quantified by measuring the BMD.

Ⅴ. CONCLUSION

The purpose of this study was to analyze the influence of presence of tooth, sex and age on the bone quality in different tooth regions of the jaw bone using Micro_CT. Thirty ninemandible (mean age 72.3±12.6 years) and thirty eight maxillae (mean age 68.1±15.2 years) were scanned (micro-CT) and three dimensionally reconstructed. Sections were made parallel to the axis of each tooth. Trabecular bone ratio (TBR) were calculated, and statistically analyzed (t-test, ANOVA, $p<0.05$). The results of this study are as follows.

1. Mandible

1) The TBR of mandible in all tooth regions was greater in dentate than in edentulous. In the dentate mandible, the TBR reduced gradually from the incisor region to the premolar region, and then increased gradually towards the molar region. In the edentulous mandible, the TBR reduced gradually from the central incisor region to the molar region.

2) In all tooth regions of dentate and edentulous it was higher in males than in females. Especially, the TBR of edentulous female group was seen difference glaringly about average 10% than man.

3) According as age increases, the TBR in dentate regions reduced monotonically in the incisor and premolar regions of dentate mandibles, but in the molar region the variation was nonmonotonic. Edentulous mandibles generally showed nonmonotonic variations in the TBR.

2. Maxilla

1) Comparing data between dentate and edentulous regions revealed a contrast between anterior teeth regions (incisor and canine regions) and

posterior teeth regions (premolar and molar regions). The TBR was higher in the dentate than in the edentulous anterior teeth region, but it was higher in the edentulous posterior teeth region.

2) In dentate maxilla, the TBR in lateral incisor, canine, second premolar and first molar region was higher in males than in females. In edentulous maxilla, the TBR of all regions except for lateral incisors were higher in males than in females.

3) According as age increases, the variations in TBR were more consistently monotonic in dentate maxillae than in edentulous maxillae. In dentate maxillae, the TBR reduced monotonically in the incisor region, but in the canine, premolar, and molar regions the variation was nonmonotonic. In edentulous maxillae, the TBR reduced monotonically in the molar and first premolar regions, but in other regions the variations were nonmonotonic.

3. Comparison between mandible and maxillae

In dentate, the TBR was significantly higher in the maxilla than in the mandible between central incisor and lateral incisor, but higher in the mandible than maxilla from first premolar to first molar. In edentuilous, the TBR was significantly higher in the maxilla than in the mandible from second premolar to second molar.

Reference

Amorim MA, Takayama L, Jorgetti V, Pereira RM: Comparative study of axial and femoral bone mineral density and parameters of mandibular bone quality in patients receiving dental implants. *Osteoporos Int* 18: 703-709, 2007.

Boyde A. Kingsmill VJ: Age changes in bone. *Gerodontology* 15: 25-34, 1998.

Choel L, Last D, Duboeuf F, Seurin MJ, Lissac M, Briguet A: Guillot G. Trabecular alveolar bone microarchitecture in the human mandible using high resolution magnetic resonance imaging. *Dentomaxillofac Radiol* 33: 177-182, 2004.

de Oliveira RC, Leles CR, Normanha LM, Lindh C, Ribeiro-Rotta RF: Assessments of trabecular bone density at implant sites on CT images. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 105: 231-238, 2008.

Dharmar S: Locating the mandibular canal in panoramic radiographs. *Int J Oral Maxillofac Implants* 12: 113-117, 1997.

Fanuscu MI, Chang TL: Three-dimensional morphometric analysis of human cadaver bone: microstructural data from maxilla and mandible. *Clin Oral Implants Res* 15: 213-218, 2004.

Glowacki J: Impact of postmenopausal osteoporosis on the oral and maxillofacial surgery patient. *Oral Maxillofac Surg Clin North Am*

19: 187-198, 2007

Gordan GS, Genant HK: The aging skeleton. *Clin Geriatr Med* 1: 95-118. 1985

Gulsahi A, Yuzugullu B, Imirzalioglu P, Genc Y: Assessment of panoramic radiomorphometric indices in Turkish patients of different age groups, gender and dental status. *Dento maxillofac Radiol* 37: 288-292, 2008.

Hu KS, Yun HS, Hur MS, Kwon HJ, Abe S, Kim HJ: Branching patterns and intraosseous course of the mental nerve. *J Oral Maxillofac Surg* 65: 2288-2294, 2007.

Hur MS, Kim JK, Hu KS, Bae HE, Park HS, Kim HJ: Clinical implications of the topography and distribution of the posterior superior alveolar artery. *J Craniofac Surg* 20: 551-554, 2009.

Iwasaki-Hayashi Y, Iida J, Warita H, Soma K: Effects of occlusal hypofunction on the microvasculature and endothelin expression in the periodontal ligaments of rat molars. *Orthodontic Waves* 60: 373-380, 2001.

Kieser J, Kieser D, Hauman T: The course and distribution of the inferior alveolar nerve in the edentulous mandible. *J Craniofac Surg* 16: 6-9, 2005.

Kieser JA, Paulin M, Law B: Intrabony course of the inferior alveolar nerve in the edentulous mandible. *Clin Anat* 17: 107-111, 2004.

Klemetti E, Vainio , Lassila V: Mineral density in the mandibles of partially and totally edentate women. *Scand J Dent Res* 102: 64-67, 1994a.

Klemetti E, Vainio P, Kröger H: Muscel strength and mineral densities in the mandible. *Gerodontology* 11: 76-79, 1994b.

Krolner B, Toft B. Vertebral bone loss: an unheeded side effect of therapeutic bed rest. *Clin Sci* 64: 537-40, 1983

Lindh C, Nilsson M, Klinge B, Petersson A: Quantitative computed tomography of trabecular bone in the mandible. *Dento maxillofac Radiol* 25: 146-150, 1996.

Lindh C, Petersson A, Rohlin M: Assessment of the trabecular pattern before endosseous implant treatment: diagnostic outcome of periapical radiography in the mandible. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 82: 335-343, 1996.

Mazes RB: On aging bone loss. *Clin Orthop* 165: 239-252, 1982.

Moon HS, Won YY, Kim KD, Ruprecht A, Kim HJ, Kook HK, Chung MK: The three-dimensional microstructure of the trabecular bone in the mandible. *Surg Radiol Anat* 26: 466-473, 2004.

Muramoto T, Takano Y, Soma K: Time-related changes in periodontal mechanoreceptors in rat molars after the loss of occlusal stimuli. *Arch Histol Cytol* 63: 369 – 380, 2000.

Neiva RF, Gapski R, Wang HL: Morphometric analysis of implant-related anatomy in Caucasian skulls. *J Periodontol* 75: 1061-1067, 2004.

Nimigean V, Nimigean VR, Maru N, Salavastru DI, Badita D, Tuculina MJ: The maxillary sinus floor in the oral implantology. *Rom J Morphol Embryol* 49: 485-489, 2008.

Nomura A: Alveolar bone changes due to loss of masticatory stress. *Jpn J Oral Biol* 24: 951-977, 1982.

Nomura T, Katz JL, Powers MP, Saito C: A micromechanical elastic property study of trabecular bone in the human mandible. *J Mater Sci Mater Med* 18: 629-633, 2007.

Rosenquist JB, Baylink DJ, Berger JS: Alveolar atrophy and decreased skeletal mass of the radius. *Int J Oral Surg* 7: 479-481, 1978.

Shapurian T, Damoulis PD, Reiser GM, Griffin TJ, Rand WM: Quantitative evaluation of bone density using the Hounsfield index. *Int J Oral Maxillofac Implants* 21: 290-297, 2006.

Solar P, Ulm CW, Thornton B, Matejka M: Sex- related differences in the bone mineral density of atrophic mandibles. *J Prosthet Dent* 71: 345-349, 1994.

Standring S, Ellis H, Healy J, Johnson D: Gray's anatomy (ed 39). London, Elsevier, pp87-95, 2005.

Taguchi A, Tanimoto K, Akagawa Y, Suei Y, Wada T, Rohlin M: Trabecular bone pattern of the mandible. Comparison of panoramic radiography with computed tomography. *Dento maxillofac Radiol* 26: 85-89, 1997a.

Taguchi A, Tanimoto K, Suei Y, Otani K, Wadamoto M, Akagawa Y, Wada T, Rohlin M: Observer agreement in the assessment of mandibular trabecular bone pattern from panoramic radiographs. *Dento maxillofac Radiol* 26: 90-94, 1997b.

Tanaka A, Iida J, Soma K: Effect of hypofunction on the microvasculature in the periodontal ligament of the rat molar. *Orthodontic Waves* 57: 180 - 188, 1998.

Toyooka E, Tanaka M, Kohono S, Ozawa H, Ejiri S: Changes of rat alveolar bone following loss of antagonistic tooth and the influence of estrogen deficiency on the changes - Analysis using micro focus x-ray computed tomography. *J Jpn Soc Bone Morphometry* 11: 53 - 61, 2001.

Turkyilmaz I, Tozum TF, Tumer C. Bone density assessments of oral implant sites using computerized tomography. *J Oral Rehabil* 34: 267-272, 2007.

Ulm C, Kneissel M, Schedle A, Solar P, Matejka M, Schneider B, Donath K: Characteristic features of trabecular bone in edentulous maxillae. *Clin Oral Implants Res* 10: 459-467, 1999.

Ulm CW, Kneissel M, Hahn M, Solar P, Matejka M, Donath K: Characteristics of the cancellous bone of edentulous mandibles. *Clin Oral Implants Res* 8: 125-130, 1997.

Ulm CW, Solar P, Ulm MR, Matejka M: Sex-related changes in the bone mineral content of atrophic mandibles. *Calcif Tissue Int* 54: 203-207, 1994.

von Wowern N, Stoltze K: Sex and age differences in bone morphology of mandibles. *Scand J Dent Res* 86: 478-485, 1978.

Abstract (in korean)

한국인에서 Micro-CT를 이용한 나이, 성별, 치아유무에 따른 골밀도 변화

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김 성 현

뼈무기질의 감소는 뼈의 일반적인 구조를 유지하는데 중요한 역할을 하는 겉질뼈 또는 해면뼈의 잔기둥뼈 부위가 감소하는 것과 유사하다. 뼈무기질의 감소는 치아의 손실 및 성별, 연령의 증가와 상관관계가 있다고 보고되어졌으나, 대부분의 연구는 방사선 촬영을 이용하여 분석되었다. 파노라마 영상을 이용한 연구결과에서는 상의 왜곡이 심하고, 낮은 해상도로 인하여 분석할 수 있는 자료가 제한됨으로써 연구의 통계치가 일반화되기 어려웠다. 따라서 연구결과의 통계치가 일반화되기 쉽고, 뼈의 미세구조를 명확히 구분할 수 있는 장치의 사용이 필요하다. 뿐만 아니라 이러한 뼈의 무기질의 분석에 대한 연구 자료는 한국인을 대상으로 한 예는 드물다. 따라서 이 연구의 목적은 한국인의 턱뼈를 대상으로 미세컴퓨터단층촬영기 (micro-CT)를 사용하여 턱뼈의 잔기둥뼈 양상을 분석하는 데 있다.

연구재료로는 한국인 위턱뼈 38쪽, 아래턱뼈 39쪽을 사용하였다. 표본을 미세컴퓨터단층촬영을 통해 촬영 및 3차원 재구성하여 각 치아부위별마다 볼쪽에서 혀쪽으로 수직으로 자른 단면사진을 얻어 분석하였다. 이 단면 사진에서 잔기둥뼈양이 차지하는 비율을 측정하고, t-test 및 일원분산법 (ANOVA)으로 통계처리 하였다.

잔기둥뼈양은 치아의 유무에 따라서 아래턱뼈는 큰어금니부위가 통계적으로 유의하였으며, 위턱뼈는 첫째큰어금니부위가 통계적으로 유의하였다. 치아가 없는 경우 위턱뼈 및 아래턱뼈는 남자가 여자보다 잔기둥뼈 양의 평균값이 모든 치아

에서 높게 나타났다. 그리고 치아가 있는 아래턱뼈는 연령이 증가할 때 점차적으로 잔기둥뼁양이 감소하였으며, 치아가 없는 경우는 그렇지 않았다. 이러한 결과들은 잔기둥뼈양이 특정부위의 치아에서 발현되는 치아의 유무, 성별의 차이, 연령의 증가와 같은 유의한 요소에 따라서 변화할 수 있다고 할 수 있다.

핵심되는 말: 아래턱뼈, 위턱뼈, 치과임플란트, 잔기둥뼈, 유치악, 무치악, 성별, 나이, 미세컴퓨터단층촬영기