Bone changes around the maxillary posterior teeth opposing the implants in mandible: a clinical study

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Purpose: When the edentulous area is restored by implant prostheses, the opposing hypofunctioned teeth will receive physiologic mechanical stimuli. This study evaluated the bone changes around the maxillary teeth opposing an implant restoration installed in the mandibular posterior area. **Materials and Methods:** Radiographs of the opposing teeth were taken at prostheses delivery (baseline), 3 and 6 months later. A customized film holding device was fabricated to standardize the projection geometry for the serial radiographs of the opposing teeth. The gray values of the region of interest of each digital image were compared according to time. Repeated measured analysis of variance was performed at the 95% significance level. **Results:** The gray values of the alveolar bone around the antagonist teeth of implants increased with time. The changes in gray values of the middle area were greater than those of the crestal area. However, the gray values of the mesial and distal areas were not different. The changes in gray values were different according to the unloaded time. **Conclusion:** A change in bone tissue will occur if a proper physiologic load is again applied to the bone tissues around a hypofunctioned tooth. (*J Dent Rehabil Appl Sci* 2015;31(4):301-9)

Key words: hypofunction; implant; bone remodeling; gray value

Introduction

Bone is a physiologically dynamic tissue that undergoes constant resorption and apposition as a response to a complex array of mechanical, bioelectrical, metabolic and local stimuli.¹ Bone tissue is the most resistant structure to an applied mechanical load. This description of the dynamic structure-function relationship between the bone and mechanical load is known as Wolff's law.²

Frost suggested in his mechanostat theory that a change in bone mass results from the mechanical use of the bone structure.³ He classified the degree

of load into a slight load, physiologic load, overload, and pathological load. When a mechanical load in the physiologic range is applied to the bone tissues, the tissues proliferate while an overload leads to bone resorption.

There has been considerable effort made to observe the bone responses of the teeth and implants. Steflik et al.⁴ examined the bone tissues around the implants in the mandible of dogs over a 6 - 24 month period. They concluded continuous loading resulted in remodeling similar to the lamina dura without a periodontal ligament. Romanos et al.⁵ compared the bone tissue changes in a monkey's mandible accord-

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ing to loading times; non-loading group, loading group after 3 months after implantation and immediate loading group. Cancellous bones with connective tissues were observed in the implant interface of the non-loading group while thick cortical bone with trabecular bone formation was noted in the loading group. This means that a proper loading to the implant is essential for inducing bone formation around the implant.

Johnson⁶ compared the results of hypofunction and hyperfunction in rats. Occlusal hypofunction was initiated by the extraction of antagonist teeth. The contralateral teeth were used as a control, even though it likely experienced hyperfunction. The hyperfunction resulted in an increase in transseptal ligament thickness but a decrease in new bone thickness. In contrast, hypofunction resulted in increased new bone thickness and decreased transseptal ligament thickness. In Kinoshita et al.'s rat experiment,⁷ extraction of the antagonist caused the eruption of teeth and a decrease in the height of the alveolar crest. From this result, it can be known that the normal functional activity of the teeth is important for maintaining the structural integrity and mechanical strength of the supporting tissues.

Bone is constantly remodeling itself in response to occlusal stimuli and other factors.^{8,9} When the teeth are extracted, the antagonist teeth are in a non-function or hypofunction state for several months. This situation is especially related to implant restoration, because of 3 to 6 months waiting for osseointegration of implants. After implants prosthesis was inserted, a load was applied by the antagonist teeth. The teeth perform a normal function with the mechanical stimulus to the bone tissues around the implant. The bone tissues are expected to change if a physiologic load by the restoration works again on the bone tissues around the antagonist teeth. However, to the best of our knowledge, there are no reports on the bone changes around the natural teeth opposing newly fitted prostheses including implant prostheses or conventional prostheses. Therefore, this study evaluated the bone changes around the maxillary teeth opposing an implant restoration installed in the mandibular posterior area. The pur-

pose of this study was to investigate the response of bones according to the functional state. The second objective of this study was to compare the changes in bone density around the teeth depending on the site and unloaded period.

Materials and Methods

In this study, human subjects were recruited according to their need to restore missing teeth. Twenty four consecutively treated human subjects were included in this report (mean age 46.2 ± 13.3 ; 62.6% female). All the subjects were treated at the Department of Prosthodontics, Gangneung-Wonju National University Dental Hospital. The experimental protocol was approved by the Gangneung-Wonju National University Institutional Review Board (IRB-2008-7).

The inclusion criteria for the subjects were good health, a need for implant installation in the posterior region of the mandible. No subjects had thickened periodontal ligament, severe alveolar bone loss, rarefying osteitis or condensing osteitis. In addition, oral parafunction such as bruxism was not found and oral hygiene status was well maintained with the absence of residual probing depths (> 3 mm) and a modified Plaque Index of 0 or 1 in the subjects. Twenty four patients received one or two implants at one side of mandible (Table 1). A total of 44 digital radiographic images were taken of 24 patients. Based on oral examination and interview about the past dental history, the unloaded periods and causes of missing teeth were recorded. Unloaded periods were classified into 3 classes (Class 1: less than 6 months, Class 2: from 6 to < 12 months, and Class 3: 12 months or more).

A customized film holding device was fabricated to obtain reproducible images. With this device, the projection geometry including the film, object and X-ray generator could be standardized. This device was fabricated by applying clear acrylic resin (Orthojet, Lang dental Mfg. Wheeling, USA) to the area between the bite block of the CCD sensor and the XCP apparatus (Fig. 1). During the fabrication procedure, the device was located as parallel as possible to the root of the tooth.^{10,11} Moreover, it was aligned

Table 1. The information of the patients

Patient	Measurement site	Opposing implants	Condition of teeth	Unloaded period (month)
1	#25MD, 26MD	#35i, #36i	natural teeth	9
2	#27MD	#37i	restored with crown	11
3	#16MD, 17MD	#46i, #47i	restored with crown	5
4	#27MD	#37i	restored with crown	9
5	#17MD	#47i	natural teeth	9
6	#26MD, 27D	#36i, #37i	natural teeth	9
7	#25MD, 26MD, 27D	#36i, #37i	natural teeth	10
8	#17MD	#47i	restored with crown	11
9	#15D, 16MD	#46i	natural teeth	9
10	#16D, 17MD	#46i	restored with crown	9
11	#26D, 27MD	#37i	natural teeth	12
12	#24D, 25MD	#35i	natural teeth	24
13	#26D, 27MD	#37i	natural teeth	9
14	#24D, 25MD	#35i	restored with crown	12
15	#16MD, 17MD	#46i, #47i	restored with crown	9
16	#16D, 17MD	#47i	natural teeth	12
17	#26D, 27MD	#37i	natural teeth	13
18	#26MD, 27MD	#36i, #37i	natural teeth	5
19	#251MD, 26MD	#35i, #36i	natural teeth	5
20	1#16MD	#46i	natural teeth	9
21	#26D, 27MD	#37i	natural teeth	5
22	#15D, 16MD	#46i	natural teeth	15
23	#26MD, 27MD	#36i, #37i	natural teeth	13
24	#26MD, 27MD	#36i, #37i	restored with crown	5

M, mesial site; D, distal site.

Fig. 1. Customized film holding device.

to include the implants and opposing teeth. Then, it was relined with the clear resin to obtain better access to the patient's mouth.

The radiographs were obtained at three time periods: at baseline, 3 months (turnover period of the bone structure) and 6 months.¹² Digital images were acquired using an intra-oral X-ray (CDxView, Biomedisys, Seoul, Korea) with a 1.5 mega-pixel resolution. A sensor with a sensor size of $41 \times 29 \times 5.3$ mm and an sensor active area of 37×27 mm was used. Radiography was carried out under standardizing conditions of 60 kV, 10 mA and 0.4 second exposure time. The digital images were saved as BMP files.

Occlusion of the implant prosthesis was observed to have occlusal contact similar to the contra-lateral tooth in contrast to the concept of the conventional implant prosthesis in a hypooclusion state.¹³ The oc-

clusal contact was made in checking with Shimstock occlusion foil (Roeko GmbH, Langenau, Germany), which had stable centric occlusal stops with light occluding force and no contacts in eccentric mandibular movement. The peri-implant bone changes were evaluated on Photoshop software (Adobe Photoshop 7.0, Adobe, Seattle, USA). The digital images were converted to a gray value of 256 levels to allow visualization. All black color was set at 0 gray value, while all white color was set at 256 gray value. The gray value for the region of interest (ROI) was determined from an average of 3 measurement times.^{14,15}

The area around the root of the maxillary molar opposing implants was considered to be the test ROI. Due to the occlusal contact with implant prosthesis, the test ROI would be in a newly functional state. The alveolar bone area around the root of the maxillary molar opposing the natural teeth was regarded as the control ROI because it received continuous functional activity. Four ROI per tooth were selected; mesial and distal sites of the crestal areas (0.1 - 0.2 mm area below the alveolar crest) and the middle areas (3 mm area below the alveolar crest). When selecting ROI, the cortical bone and lamina dura need to be included in the crestal areas and lamina dura in the middle areas. The size of the ROI was 23×23 pixels, which corresponded to a $1 \text{ mm} \times 1 \text{ mm}$ square (Fig. 2).

Fig. 2. Regions of interest (ROI). Black box, control group; White box, test group.

Blinded examiner measured all the images in a random sequence. The reproducibility of selecting the ROI was evaluated by intra-examiner calibration. In a single digital image, the ROI was selected 15 times. The standard deviations of the X- and Y- coordinates and of the gray value were estimated. After confirming the reproducibility of the selection of the ROI, the gray values of the ROI were measured three times and the mean gray value was calculated.

Statistical analysis

The resulting data were subjected to repeated measured ANOVA to compare the gray values of the ROI according to the time interval. The changes in gray values in the test and control ROI were compared. The mesial and distal, crestal and middle areas in the test ROI were compared. Duncan's multiple range test was used for post-hoc comparisons. Statistical significance was set at $\alpha = 0.05$.

Results

All implants were successfully functioned without any complication during observation time.

The standard deviations of the selecting area were 0.0080 in X-coordinates and 0.0052 in Y-coordinates. Selection of the ROI was considered reproducible. The standard deviation of the gray value was 1.74.

Table 2 and 3 presents the mean gray value changes in the test and control groups. The changes in gray value of the test ROI were significantly higher than that of the control ROI ($P = 0.001$, Fig. 3). The gray value of the test ROI increased with time ($P = 0.000$). On the other hand, the gray value of the control ROI increased slightly, however the difference was not significant ($P = 0.222$). The changes in the gray value were greater in the first 3 months than in the next 3 months.

In Table 4 and 5, the gray values of different ROIs of the test ROI are presented. The gray value changes in the middle area were greater than those in the crestal area ($P = 0.033$). However, the gray value of the mesial site was similar to that of the distal site ($P = 0.354$). The changes in the 4 selected areas were

Table 2. Means (SDs) for gray values of the control and test group

Group	N	Time		
		Baseline	3 months	6 months
Control	66	109.9 (35.5)	111.2 (34.9)	112.9 (37.4)
Test	69	113.4 (38.3)	120.5 (39.2)	125.1 (40.9)

SD, standard deviation.

Table 3. Means (SDs) for changes in gray value changes with time lapse of the control and test group

Group	N	Time	
		3 months	6 months
Control	66	1.3 (5.3)	3.0 (12.7)
Test	69	7.2 (10.1)	8.1 (13.8)

SD, standard deviation.

Fig. 3. Radiographic images of different time interval (A) baseline, (B) 3 months after restoration, (C) 6 months after restoration.

Table 4. Means (SDs) for gray values in the region of interest

Group		N	Time		
			Baseline	3 months	6 months
Crestal	Mesial	27	107.0 (37.7)	113.2 (40.4)	117.3 (41.6)
	Distal	38	111.5 (39.4)	119.1 (39.6)	123.3 (40.5)
Middle	Mesial	30	115.0 (40.7)	120.8 (40.3)	124.6 (43.0)
	Distal	39	118.9 (36.3)	127.3 (37.5)	133.2 (39.1)

SD, standard deviation.

Table 5. Means (SDs) for gray value changes with time lapse in the region of interest

Group		N	Time	
			3 months	6 months
Crestal	Mesial	27	6.2 (11.5)	10.3 (14.1)
	Distal	38	7.7 (10.8)	11.7 (14.5)
Middle	Mesial	30	5.7 (9.1)	9.5 (13.2)
	Distal	39	8.4 (9.2)	8.1 (13.4)

SD, standard deviation.

similar regardless of the ROI ($P = 0.553$).

The gray value for Class 3 (unloaded period of 12 months or more) was significantly lower than that for the other classes at baseline ($P = 0.016$). However, the changes in the gray value were greater in Class 3 than in the other classes. Moreover, this trend was also maintained during the next 3 months (Fig. 4).

Fig. 4. Changes in gray values according to the unloaded period.

Discussion

In this study, continuously functioning teeth were selected as the control ROI. In this group, physiologic stress continuously worked on the lamina dura and surrounding alveolar bone. Therefore, no bony changes were expected. According to Frost³ and Kinoshita et al.,⁷ a normal functional activity of the teeth is essential for the mechanical strength of the supporting. The gray values of the control ROI increased slightly. If there is a unilateral loss of teeth, the preferred chewing side of the individual may change. These individuals probably try to avoid masticating on that side including the edentulous area. As a result, the teeth adjacent to the opposing edentulous area can be rendered into a slight hypofunctional state. Restoring the opposing edentulous area can lead to a slight increase in function of the adjacent teeth.

The test ROI did not maintain a normal function for 5 - 24 months due to a missing mandibular molar. During this period, the bone mass might be reduced due to a lack of the mechanical stimulus for maintaining the bone tissue.⁷ If a mechanical stimulus applied with the implants in the opposite arch, a proper physiologic load worked again in the bone tissues around the hypofunctioned tooth root and a change in bone tissue was assumed to occur. This hypothesis was proved in this study. In the test ROI, the gray value increased after 3 months compared with the baseline.

Although the turnover period of the bone structure is affected by age, disease and metabolic state, it takes approximately 10 weeks.¹² Therefore, the observation period was set to 6 months for bone change of the antagonist teeth of the implant. However, the gray values were changed after 3 months. This might be caused by the fact that a normal occlusal force rather than the weaker occlusal force was established in the implant prosthesis. The occlusion of implants prosthesis is usually established to have hypo-occlusion in order to avoid the overload.¹³ However, there was no adverse effect like on the implant during the observation period in this study.

In the region receiving the compressive force, the

action of osteoblasts and osteoclasts leads to remodeling of the alveolar bone.^{5,6,14} Therefore, it is possible that the changes in gray value would be different by the evaluation site. In this study, the crestal area and middle area of the antagonist teeth were selected as a ROI because the masticatory load would concentrate on the cervical area under the cusp rather than the root apex.¹⁶ In addition, the palates of some patients were too shallow to locate the customized film holding device reproducibly. Therefore, the root apex was excluded as the ROI.

The changes in the gray value of the middle area were greater than those of the crestal area. This result might be due to the distribution of occlusal forces. Occlusal forces are transmitted from the occlusal surface to the root surface, and then to the adjacent alveolar bone.¹⁶ In this process, the occlusal forces may be concentrated at the center of the root rather than at the crestal area. As was observed in the study by Romanos et al.,⁵ the cortical bone is more actively remodeled after restoration than the cancellous bone. In addition, the gingival inflammation can negatively influence on the crestal bone area, while the mechanical load itself can affect the middle area.

As the teeth showed slight mesial inclination, it was thought that the occlusal stress might be concentrated on the mesial region of the teeth. However, there was no difference between the mesial and distal site. This means that the stress was not concentrated on a mesial or distal area. In this study, occlusal contact points were established on the center of the implant prosthesis. Moreover, the lateral contact points were eliminated in excursive movement. Therefore, a vertically oriented force might be transmitted to the implant fixture and antagonist teeth.

As suggested by Frost,³ functional activity of the teeth is essential for maintaining the bone tissue. The bone density around the teeth which were in a hypofunctional state for a longer time period (unloaded period of 12 months or more) was lower than that around the teeth which were in a hypofunctional state for a shorter time period. However, the tendency for an increase in the bone density around the teeth which were in a hypofunctional state for a longer time period was similar to that around the teeth

which were in a hypofunctional state for a shorter time period. It means that the reactivity for changes in the mechanical demands was similar in both types of teeth regardless of the length of the edentulous period. In addition, active bone remodeling continued after 3 months. The possibility of restoring bone density with a time lapse could not be eliminated due to the increase in the gradient of bone changes. However, a longer observation period would be needed in order to identify the exact tendency of bone changes.

In some ROIs, the gray values at 3 and 6 months were lower than that of the baseline. A subtle difference in the locational relationships of the subject, CCD sensor and x-ray tube would alter the superimposition in anatomic structure (trabecular pattern, soft tissue and others) of the ROI. Intra-examiner variation was unavoidable, even though one examiner measured the gray value 3 times in setting the ROI.¹⁵ In analyzing the change in the radiographic density, standardization of the radiographic density is important by controlling the exposure time, angulation of the x-ray tube and processing condition.^{10,11,17} In this study, the relationship of the CCD sensor and x-ray tube was reproducible due to using a customized film holding device. The exposure condition was kept the same, and the average of 3 measurements was calculated. Moreover, the processing errors of the radiographic image were excluded using a CCD sensor.

This study showed that bone changes around the maxillary molar were significant because the load by the implants prosthesis works in hypofunctioning teeth. However, the difference in bone changes according to the evaluation site was not defined. Further studies with a long-term observation period will be necessary to evaluate the bone tissue changes accurately and quantitatively.

Conclusion

Within the limitations of this study, the density of the surrounding bone of the antagonist teeth to the implant increased after prosthetic restoration. This finding concurs with the hypothesis that a proper physiologic load worked on the bone tissues around

the hypofunctioned tooth that caused changes in bone tissue.

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하악 임플란트에 대합되는 상악 구치의 주변골 변화에 대한 임상연구

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목적: 무치악 부위를 임플란트 보철로 수복하면 기능저하 상태였던 대합치는 생리적인 자극을 받게 된다. 본 연구는 하악 구치부 임플란트에 대합되는 상악치아의 골변화를 평가하였다.

연구 재료 및 방법: 보철물 장착시(기준점) 및 3, 6개월 후에 방사선 사진을 채득하였다. 맞춤형 필름유지기구를 제작하여 대합치의 연속적인 방사선 사진에 대한 투사를 표준화하였다. 디지털사진에서 관심부위에 대한 그레이수치를 시간별로 측정하여 95% 유의수준으로 반복측정분산분석으로 통계적 유의성을 검증하였다.

결과: 대합치의 그레이수치는 시간이 흐름에 따라 증가하였다. 치조정부위보다 중양부위의 변화가 더 컸으나 근심과 원심의 그레이수치는 큰 차이를 나타내지 않았다. 그레이수치의 변화는 하중을 가하지 않았던 기간에 따라 다른 양상을 나타내었다.

결론: 기능저하였던 치아주변의 골조직에 기능적 하중이 가해지면 골조직의 변화가 발생할 수 있는 것으로 사료된다.
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주요어: 기능저하; 임플란트; 골재형성; 그레이수치

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