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Original Article

Influence of occlusal height for an implant prosthesis on the periodontal tissues of the antagonist

Koko Hoshino, Hiroyuki Miura, Osamu Morikawa, Hitoshi Kato, Daizo Okada and Toshiyuki Shinki

Fixed Prosthodontics, Department of Restorative Sciences, Division of Oral Health Sciences, Graduate School, Tokyo Medical and Dental University

The purpose of this study was to investigate a suitable occlusal height for an implant prosthesis by examining the responses of the periodontal tissues around a natural antagonist. The subjects were three Japanese females with two posterior missing teeth restored by ITI system implants (Straumann). Two kinds of experimental implant prostheses were adjusted as follows; one was adjusted in heavy clenching (HC), and the other was adjusted in light clenching (LC). The periodontal pulsation, displacement during biting an occlusal force meter and the mobility of the antagonist were measured before and one week after temporary cementing HC and LC, and one week after removal. In each prosthesis, there was no significant difference in the amounts of the pulsation and mobility of the antagonist before and one week after cementing, and one week after removal ($p > 0.05$). The displacement of the antagonist during biting the occlusal force meter did not change much during the conditions. The results of this study suggested that an implant prosthesis adjusted not only under heavy clenching but light clenching like crown restorations for natural teeth did not affect the periodontal tissues of the antagonist in a harmful manner.

Corresponding Author: Koko Hoshino
Fixed Prosthodontics, Department of Restorative Sciences, Division of Oral Health Sciences, Graduate School, Tokyo Medical and Dental University,
1-5-45, Yushima, Bunkyo-ku, Tokyo 113-8549, Japan
Tel: +81-3-5803-5522 Fax: +81-3-5803-0201
E-mail: hoshinok.fpro@tmd.ac.jp
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Introduction

Dental implant therapy has recently become a popular method of replacing one or more missing teeth. To maintain a good condition for a long time after the treatment, it is important that implant prostheses functionally harmonize with the stomatognathic system. Although some researchers have suggested an ideal occlusion for implant prostheses[1-8], there are few studies regarding their optimum occlusal height.

The periodontal ligament around natural teeth is composed of collagenous fiber bundles and a microvascular system, and functions viscoelastically when occlusal forces are applied[9-12]. According to this characteristic, the periodontal ligament buffers direct transmission of occlusal force to the maxillary or mandibular bone. However, dental implants do not have such a buffering system since they are not supported by a periodontal ligament. Therefore, we have to decide the occlusal height of the implant prosthesis carefully, but sufficient evidence for this has not been obtained.

The periodontal pulsation has been measured as one of the characteristics that show the functional condition of the periodontal tissues[13-24]. It has been reported that periodontal pulsation is a minute displacement of the tooth synchronized with the pulse wave of a vascular system in the periodontal ligament. Moreover the pulsation is probably affected by the blood flow and dynamic properties of the periodontal ligament[18,21], which could be changed by the occlusal condition. Accordingly, periodontal pulsation seems to have a close relation to the occlusal height.

The purpose of this study was to determine an appropriate occlusal height of the implant prosthesis by measuring the periodontal pulsation, mobility, displacement during biting the occlusal force meter and occlusal contacts of the antagonist (which were easily influenced) when the height of the prosthesis was changed.

Materials and Methods

Subjects

The subjects were three Japanese females aged 32-53 years with two posterior missing teeth. They had good periodontal conditions and an acceptable centric occlusion. We obtained the informed consent of each subject participating in the research.

The missing teeth of subject A were lower left first and second molars, those of subject B were lower right first and second molars, and those of subject C were upper left first and second molars. ITI system implants (Straumann) were placed at each edentulous region by a one-stage surgical procedure. Occlusal schema in lateral excursions of subjects A and C were group function, and that of subject B was cuspid protected occlusion. The experiments were carried out more than seven months after the placement of implants. The subject tooth was the first molar, which was the antagonist to the implant prostheses.

Experimental prostheses

Two kinds of experimental implant prostheses were made of composite resin as follows. At first, two similar crowns were fabricated with a CAD/CAM system (GN-1, GC) in each subject. After try-in in the mouth, one of the two prostheses was adjusted under heavy clenching (HC), and the other was adjusted under light clenching (LC) like crown restorations for natural teeth. Clenching intensity was mean 84% of the maximum voluntary contraction (MVC) of masseter muscles in heavy clenching, and 19% MVC in light clenching. In addition, a porcelain-fused-to-metal crown, which had been fabricated as a final prosthesis and adjusted in medium clenching (MC), was used before cementing experimental prostheses (HC and LC) and after removal. We tried to adjust all prostheses to have more than two identical occlusal contact areas, and confirmed them by an occlusal contact checking material, black silicone (Bite-Checker, GC). The occlusal contacts of the remaining teeth and the occlusal schema in lateral excursions were maintained before and after cementing the prostheses. All prostheses were cemented with temporary cement (Freegenol Temporary Pack, GC). The occlusal height of the prosthesis was confirmed by pulling out one or more strips (OCCULUSAL REGISTRATION STRIPS, ARTUS) whose thickness was 12.5 μm. In all subjects, one strip could not be pulled out in light clenching when LC was cemented. In case of HC, two to four strips, and in case of MC, one to three strips could be pulled out in light clenching. In all conditions, one strip could not be pulled out in light clenching in the adjacent tooth anterior to the implant (second premolar).

Measuring device

Periodontal pulsation can be detected as a minute displacement of the tooth, which shows the pulse wave in the periodontal microcirculation. In this study, the displacement of the tooth was measured with the two-dimensional tooth displacement transducer type K[20,21]. This measuring device consists of two pick-up heads, two magnets, a universal joint and a measuring probe (Fig. 1). Two magnet sensors (Magnesensor, SONY MAGNESCALE) were used as a transducer. These are compact, light, non-contact magnetic signal detectors. The two-dimensional movements of the end of the measuring probe are accurately transmitted to the magnets in each detective direction (bucco-lingual and corono-apical) by the universal joints and detected by each pick-up head as the voltage.

The displacement transducer type K was screwed into a splint, which was made to be parallel to the occlusal plane and fixed on the labial surface of the anterior teeth. The splint was made of an aluminum

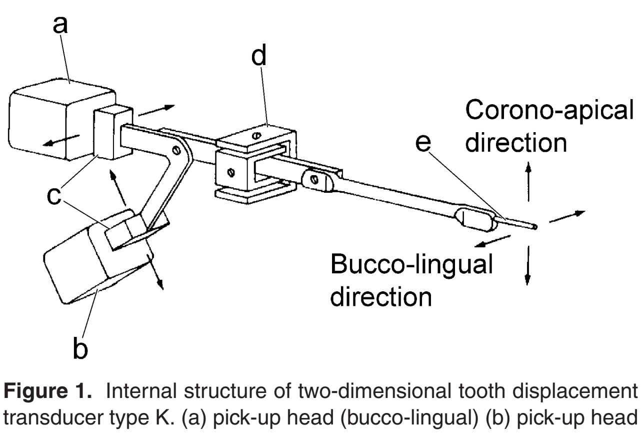

Figure 1. Internal structure of two-dimensional tooth displacement transducer type K. (a) pick-up head (bucco-lingual) (b) pick-up head (corono-apical) (c) magnet (d) universal joint (e) measuring probe.

plate and self-curing acrylic resin. Then the end of the measuring probe was attached to the center of the buccal surface of the subject tooth using a self-curing acrylic resin. All parts of the measuring device except for the measuring probe were set up extraorally, so the transducers were not affected by the intraoral environment (temperature and humidity) (Fig. 2). The linearity error of this transducer in each direction was less than 1% for a range of $\pm 200\ \mu m$, and a resolution was less than $0.05\ \mu m$.

Methods

The periodontal pulsation, displacement during biting the occlusal force meter (MPM-3000, NIHON KOHDEN) and the mobility of the subject tooth were measured before and one week after cementing HC and LC, and one week after removal. LC was cemented about one month after HC had been removed. These experiments were performed at the same time of day.

Whenever the pulsation was measured, there was no occlusal contact over the whole teeth. Initially, the pulsation was recorded without loading. And then, to detect the minute movement of the transducer caused by the pulsation of the anterior teeth, the output was recorded when the pulsation of the subject tooth was arrested with a loading appliance. This appliance was fixed on the occlusal surfaces of the first premolar and second molar, and could apply the load to the occlusal surface of the subject tooth in an apical direction with a leaf spring and screw (Fig. 3). When the pulsation was measured, an electrocardiogram (a standard limb lead I) was recorded simultaneously with surface electrodes on the left and right arm.

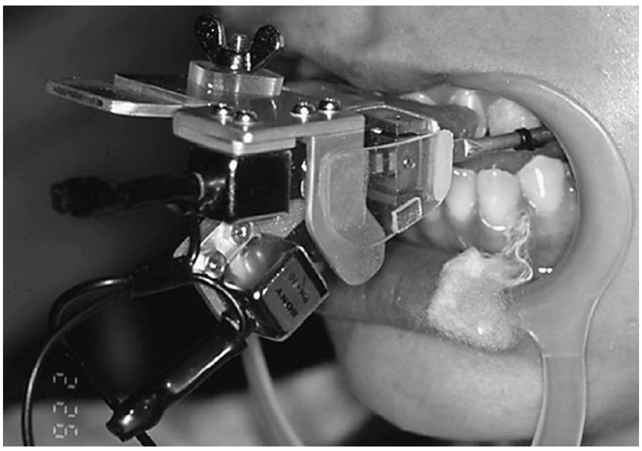

Figure 2. Measurement of tooth displacement with the two-dimensional tooth displacement transducer type K.

The two-dimensional displacement during biting the occlusal force meter was also detected with this transducer. A pair of bite tables was made of an aluminum plate and self-curing acrylic resin so that the occlusal force could be applied in the direction of the tooth axis. After these bite tables were set up on the surfaces of the subject tooth and the antagonist, the occlusal force meter was put between the bite tables (Fig. 4). With this device, the signal of the tooth displacement transducer and the occlusal force meter can be

Figure 3. The loading appliance.

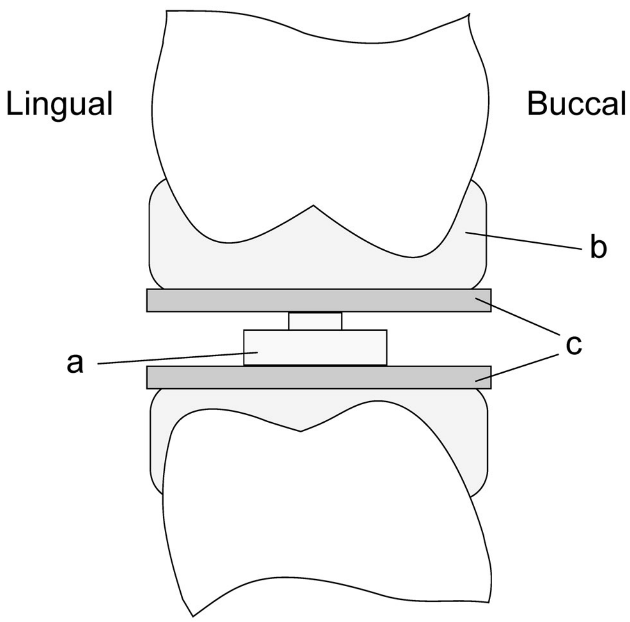

Figure 4. Measurement of the occlusal force. (a) occlusal force meter (b) resin (c) aluminum plate.

detected simultaneously.

The mobility of the subject tooth was evaluated by the Periotest® method (Periotest®, MEDIZINTECHNIK GULDEN)[25]. The trial of one measurement was performed five times.

Occlusal contacts at the intercuspal position

The occlusal contacts of the subject tooth were confirmed by taking a record with black silicone[26] during light and heavy clenching at the intercuspal position. This was carried out before and right after cementing HC and LC, one week after cementing, and one week after removal. After trimming the interocclusal record, it was set on a light box and transparent areas were photographed with a digital camera. Transparent areas were superimposed on the occlusal surface image with personal computer. In this study, the occlusal contact was defined as the occlusal adjacent area below 60 μm.

In order to monitor clenching intensity, electromyographic recordings of masseter muscles were simultaneously recorded with bipolar surface electrodes.

Data Analysis

The output signals from the transducers, the occlusal force meter, and the electrocardiogram were monitored by a rectigraph (OMNICORDER 8M15, NEC San-ei) and simultaneously recorded on a digital data recorder (PC208Ax, Sony). The data were read on a personal computer via an A/D converter (PC-Scan II, Sony) with a sampling rate of 100 Hz.

Fig. 5 shows the original data of the periodontal pulsation and the electrocardiogram. The pulsation was synchronized with the heartbeats, so we regarded R waves of the electrocardiogram as a trigger of the pulsation cycle, and then twenty cycles of the pulsation with or without loading were averaged. The pulsation with loading was considered as the movement of the transducer fixed to the anterior teeth. Therefore, we defined the pulsation of the subject tooth as the subtractive outputs of the pulsation with loading from that without loading (actual pulsation)[20]. It was displayed as a projected image of the pulsation path in the frontal plane. The mean interval between the R wave and the peak of the pulsation without loading was calculated in twenty cycles. On the data after subtraction, the point at the mean interval from the starting point was defined as the peak point of the pulsation. Amount of the pulsation was defined as the two dimensional distance between the starting point and the peak point (Fig. 6).

The amount of tooth displacement during biting the occlusal force meter was defined as the two dimensional distance between the starting point and each point on the displacement path. The starting point of the displacement was defined as the average voltage in one second when the load was not applied to the tooth just before biting.

The amount of the periodontal pulsation and the tooth mobility (Periotest® values) were statistically analyzed with one-way repeated measures analysis of variance (ANOVA) test (α = 0.05).

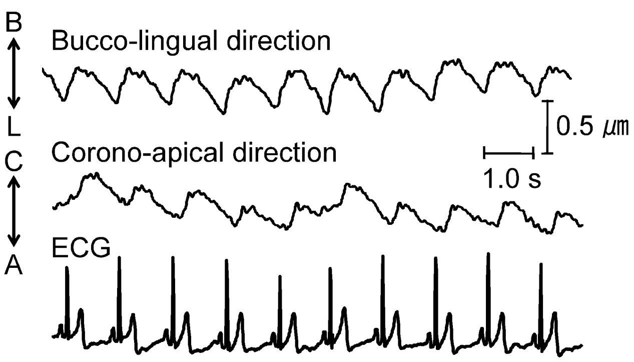

Figure 5. Original data of the periodontal pulsation and the electrocardiogram (ECG).

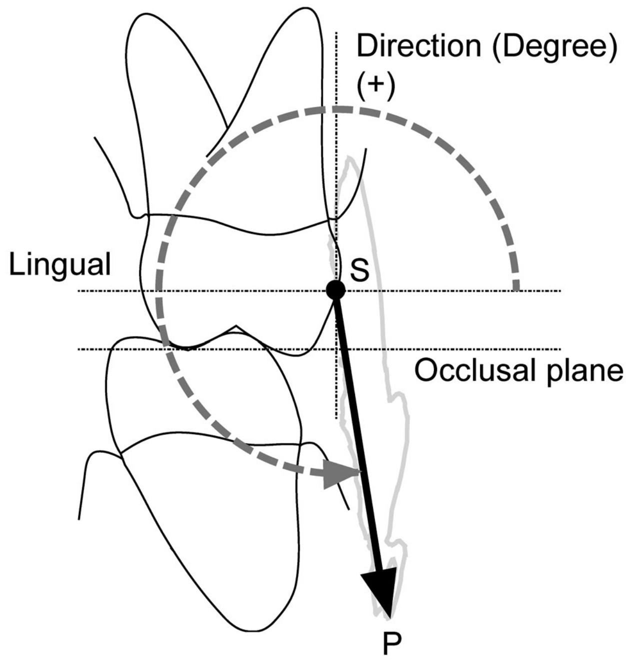

Figure 6. Definition of amount and direction of the periodontal pulsation. S: starting point, P: peak point.

Results

Table 1 shows the amount and direction of the periodontal pulsation before and one week after cementing HC and LC, and one week after removal. Fig. 7 shows the projected image of the pulsation path in the frontal plane in three subjects.

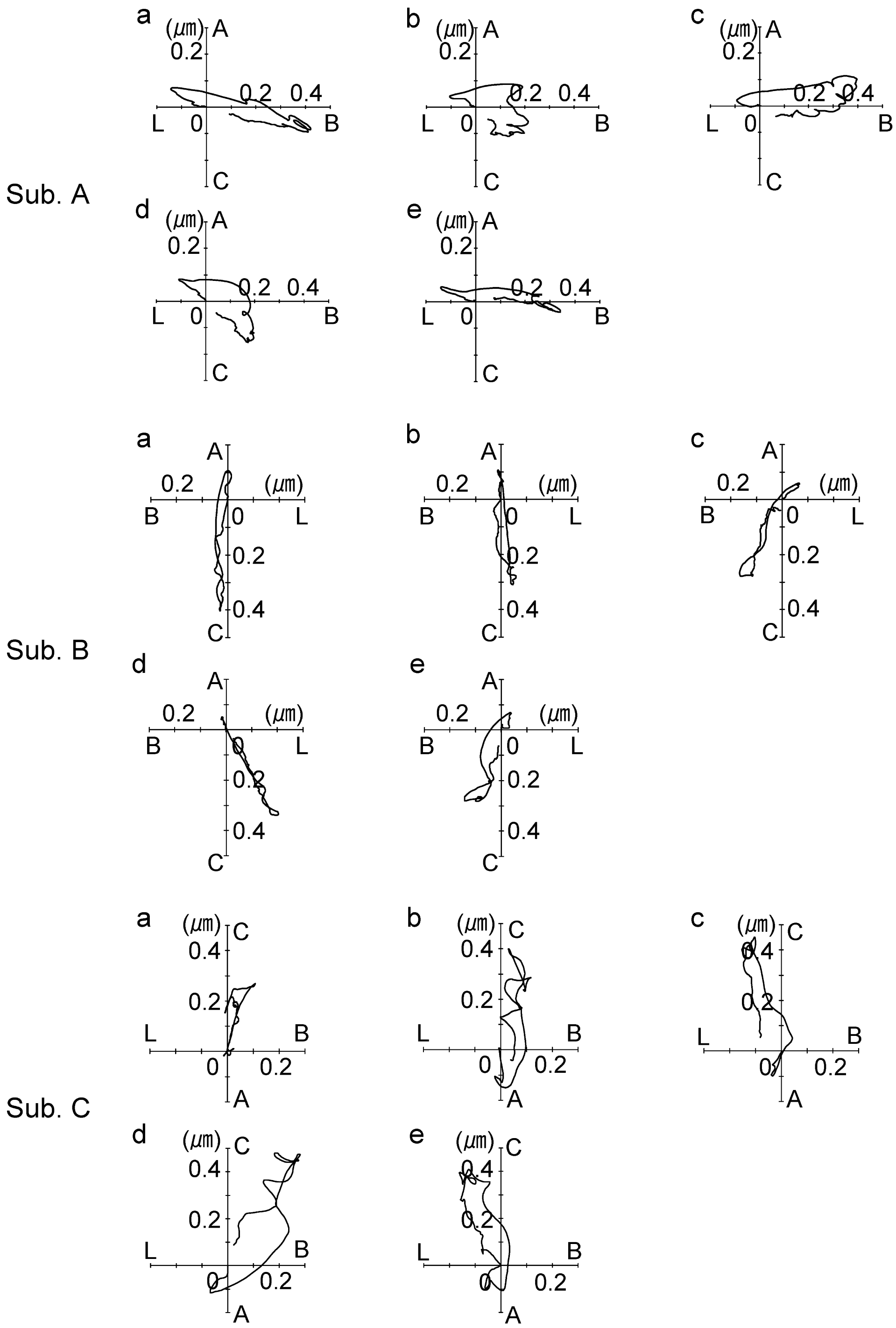

Figure 7. Projected image of the pulsation path in the frontal plane. (a) before cementing (b) 1 week after cementing HC (c) 1 week after removing HC (d) 1 week after cementing LC (e) 1 week after removing LC. A: apical, C: coronal, B: buccal, L: lingual.

Table 1. Amount and direction of the periodontal pulsation

		Sub. A		Sub. B		Sub. C	
		Amount (μm)	Direction (degree)	Amount (μm)	Direction (degree)	Amount (μm)	Direction (degree)
	Before cementing	0.33	−8	0.39	−94	0.26	74
HC	1w after cementing	0.14	3	0.31	−81	0.33	74
	1w after removing	0.36	19	0.30	−113	0.45	104
LC	1w after cementing	0.21	−24	0.37	−59	0.52	59
	1w after removing	0.25	−2	0.29	−108	0.38	112

Table 2. Mobility of the tooth (Periotest® values)

		Sub. A Upper first molar	Sub. B Upper first molar	Sub. C Lower first molar
	Before cementing	5.8 (0.4)	6.4 (0.9)	4.6 (0.5)
HC	1w after cementing	4.8 (0.4)	4.4 (0.5)	4.8 (0.4)
	1w after removing	4.0 (1.0)	5.2 (0.8)	4.0 (0.7)
LC	1w after cementing	3.8 (0.8)	3.8 (0.4)	3.8 (0.8)
	1w after removing	3.8 (0.4)	4.6 (0.9)	5.4 (0.6)

( ): S.D.

Standard Periotest® values for teeth with healthy periodontal tissues of Japanese adult woman;

Upper first molar: 7.2 (±3.5), Lower first molar: 6.2 (±2.7)

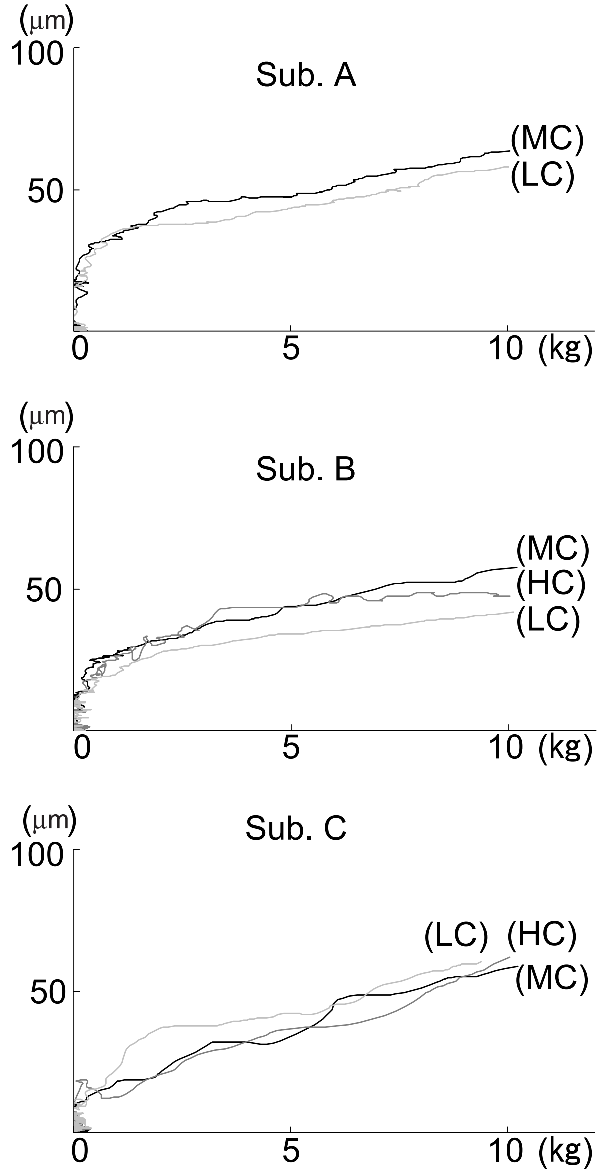

Figure 8. Stress-strain curve. The data of HC in Sub. A is not included.

In all conditions, the pulsation path was similar within the same subject. The direction of the pulsation was in a buccal direction in subject A, and a coronal direction in subjects B and C. The amount of the pulsation was 0.14–0.36 μm in subject A, 0.29–0.39 μm in subject B, and 0.26–0.52 μm in subject C. In each prosthesis (LC, HC), there was no significant difference in the amounts of the pulsation before and one week after cementing, and one week after removal ($p > 0.05$).

Fig. 8 shows the stress-strain curve (SSC) of the subject tooth, which represents a relation between the occlusal force and the amount of tooth displacement. In this study, each SSC showed similar curves composed of two phases in all subjects. Each SSC made a steep ascent until about 0.5 kg, and gradually increased. In each subject, the shape of the SSC did not change much in all conditions.

Table 2 shows the mean Periotest® values of the subject tooth. The values of each subject were within ±1SD of the mean for teeth with healthy periodontal tissues of Japanese adult woman[27]. In each prosthesis (LC, HC), there was no significant difference in the Periotest® values before and one week after cementing, and one week after removal ($p > 0.05$).

Fig. 9 shows the occlusal contacts of the subject

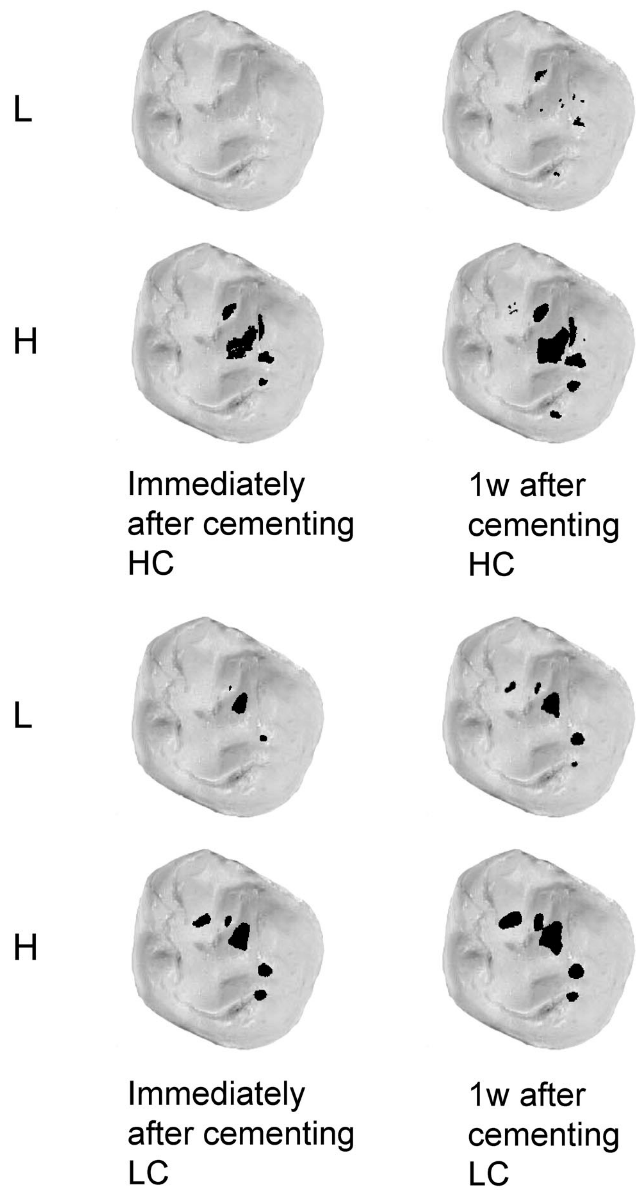

Figure 9. Occlusal contacts (occlusal adjacent area below 60 μm) of the subject tooth in light and heavy clenching (Sub. B). L: light clenching (mean 19% MVC), H: heavy clenching (mean 84% MVC).

tooth in subject B. In each subject, an obvious change of occlusal contacts was not observed between immediately and one week after cementing HC and LC like subject B. Occlusal contacts of the teeth other than subject tooth had hardly changed.

Discussion

In the case that the occlusal contacts of the prostheses are reconstructed inappropriately, it is thought that some unacceptable changes occur in a vascular system of the periodontal and pulpal tissues, dynamic properties of the periodontal ligaments according to the non-physiological force applied to the tooth[18,22,28,29]. In this study, the appropriate occlusal height of the implant prosthesis was examined by measuring the change in the periodontal pulsation, displacement, mobility, and occlusal contacts of the antagonist to the implant prosthesis.

Periodontal pulsation

Since periodontal pulsation was reported by Parfitt[13], that of the anterior and the posterior teeth has been researched[14-24]. And the amount and direction of the pulsation has been revealed. The periodontal pulsation reflects the circulatory system and dynamic properties of the periodontal tissues, so this shows some response in an early stage to a non-physiological stress such as a traumatic occlusion. Therefore, it is possible to observe a minute alteration before an irreparable change occurs in the living periodontal tissues in a non-invasive manner. In previous studies, damping or irregularity of the periodontal pulsation was found in some cases of periodontal disease[14]. And an increase or decrease of the amount of the pulsation in the first molars was observed when high prostheses were cemented[18,22]. Tanaka[18] reported that the amount of the pulsation was normally 0.4–0.9 μm. It showed a tendency to decrease two days later when a 120 μm higher prosthesis was cemented and increased about 1.4 μm three days later when a 300 μm higher prosthesis was cemented. In addition, a more than 35 μm higher prosthesis decreased masticatory efficiency and caused an irregularity of muscle activity during mastication. Therefore, as for the height of the prosthesis, these studies concluded that one up to 30 μm higher was ideal.

In this study, our data on the amount and direction of the pulsation when HC and LC were cemented are coincident with previous studies[19,21]. We had anticipated that LC was not good for the periodontal tissues of the antagonist and lead to a decrease or increase in the amount of the periodontal pulsation. However, in this study, the changes of the pulsation were smaller than those in the previous reports[18,22]. Therefore, not only HC but LC probably did not have a harmful influence on the microcirculation of the periodontal tissues around the antagonist, and the heights of these prostheses were acceptable to the periodontal tissues.

Stress-strain curve (SSC)

The SSC represents the viscoelastic properties of the periodontal tissues in function. Especially the first phase of SSC reflects the distortion of the periodontal ligaments. In this study, the SSC showed the two phases as in previous reports[30-32] in all subjects, and the shape of the first phase and the amount of displacement were similar in various conditions (HC, LC, and MC) within the same subject. Therefore, HC and LC did not affect the periodontal tissues.

Previous studies reported that the implant inserted in the molar region or the first molar without any occlusal and proximal contacts displaced several micrometers (<100 μm) during clenching[8,33,34]. These facts show that the implant displaces due to the distortion of maxillary or mandibular bone although there was no periodontal ligament around the implant. Therefore, in each case of this study, the distortion of bone and antagonist's periodontal ligament could compensate for the lack of a periodontal ligament around the implant and the difference of the height for an implant prosthesis.

Mobility of the subject tooth

The fundamental function of the Periotest® is the measurement of the periodontal damping characteristics[25], so an alteration in the dynamic properties of the periodontal tissues could be detected with the Periotest® method. The results of the Periotest® values in this study showed that neither HC nor LC caused an alteration in the dynamic properties of the periodontal ligaments around the antagonist.

Occlusal contacts

Even if the implant prosthesis was a little higher than the ideal height for the antagonist, depression of the antagonist would still occur and cancel any influence of the prosthesis height on the periodontal pulsation, SSC, and mobility of the antagonist. However, the occlusal contacts confirmed in this study indicated that neither extrusion nor depression of the subject tooth would occur. Therefore, the results of this study showed that not only the height of HC but the height of LC was acceptable for the periodontal tissues of the antagonist.

The occlusal height of the implant prosthesis

Some researchers have reported an ideal occlusion for the implant prosthesis[1-8]. Saba[5] mentioned that the most significant factor affecting occlusal stability was occlusal loading. The key to control the loading was to achieve a sufficient number of implants, occlusal guidance, which minimized any lateral forces on the implant prosthesis, suitable occlusal design, and passive fit of the framework. Regarding the occlusal height of the implant prosthesis, Davis[6] described that in the case where the occlusion was decided by the remaining teeth, the implant prosthesis should have a clearance of 30 μm in centric occlusion. This means that this prosthesis can transmit a light occlusal force under heavy clenching. On the other hand, it was reported that the height of the implant prosthesis should be equalized to the remaining natural teeth to prevent the disorder of masticatory function[7]. However, a standard based on objective data regarding occlusal height has not been established.

There was no subject who felt that the experimental prostheses were high. The tactile sensibility of implants is lower than that of natural teeth[35]. However, the tactile sensibility and mastication are controlled with the neural control mechanism of masseter muscles and the function of nerve fibers in the bone tissues and the connective tissues of peri-implant[35-38]. The results of this study suggested that not only HC but LC did not affect the periodontal tissues of the antagonist so much. Therefore, even if the implant prosthesis was adjusted in light clenching, the periodontal tissues of the natural antagonist and the neural control mechanism of masseter muscles could compensate the lack of a periodontal ligament, which caused a prospective increase in the threshold of tactile sensibility and an overload especially at the first phase of tooth displacement under light occlusal force.

If an inadequate (low height) prosthesis was cemented, occlusal balance would collapse and problems such as occlusal trauma in other regions or a decrease in masticatory efficiency would occur. We should select a method of occlusal adjustment depending on each case. However, the results of this study suggested that the periodontal tissues of the antagonist to the implant are hardly influenced even if the height of the implant prosthesis is adjusted in light or medium clenching like crown restorations for natural teeth.

Conclusions

Within the limitations of this study, the following conclusions were reached:

1. The amount of the pulsation of the antagonist to the implant was 0.14–0.52 μm and the direction of that

was mainly in a buccal or coronal direction, which was coincident with previous research. The pattern of the pulsation path was similar within the same subject.

2. No obvious change was observed in the periodontal pulsation, the stress-strain curve, the mobility and the occlusal contacts of the antagonist to the implant before and one week after cementing the implant prostheses which were adjusted under light and heavy clenching.

3. The results of this study suggested that implant prostheses adjusted not only under heavy clenching but light clenching did not affect the periodontal tissues of the antagonist to the implant in a harmful manner.

Acknowledgements

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References

1. Chapman RJ. Principles of occlusion for implant prostheses: guidelines for position, timing, and force of occlusal contacts. Quintessence Int 1989;20:473-480.
2. Dario L J. How occlusal forces change in implant patients: a clinical research report. J Am Dent Assoc 1995;126:1130-1133.
3. Weinberg LA. Therapeutic biomechanics concepts and clinical procedures to reduce implant loading. Part I. J Oral Implantol 2001;27:293-301.
4. Weinberg LA. Therapeutic biomechanics concepts and clinical procedures to reduce implant loading. Part II: therapeutic differential loading. J Oral Implantol 2001;27:302-310.
5. Saba S. Occlusal stability in implant Prosthodontics-Clinical factors to consider before implant placement. J Can Dent Assoc 2001;67:522-526.
6. Davis SJ, Gray RJM, Young MPJ. Good occlusal practice in the provision of implant borne prostheses. Br Dent J 2002;192:79-88.
7. Matsutani Y, Tanaka M, Kawazoe T. Effect of occlusal contact height on masticatory function and muscle activity in posterior unilateral osseointegrated implant bridge. (in Japanese, English abstract) Journal of Japanese Society of Oral Implantology 2003;16:18-31.
8. Morikawa O. Influence of occlusal contacts of implant on adjacent teeth and antagonists displacements. (in Japanese, English abstract) J Stomatol Soc 2003;70:224-233.
9. Mülemann HR, Zander HA. Tooth mobility (III), The mechanism of tooth mobility. J Periodontol 1954;25:128-137.
10. Picton DCA. On the part played by the socket in tooth support. Arch Oral Biol 1965;10:945-955.
11. Picton DCA, Willis DJ. Viscoelastic properties of the periodontal ligament and mucous membrane. J Prosthet Dent 1978;40:263-272.
12. Kurashima K. The viscoelastic properties of the periodontal membrane and alveolar bone. (in Japanese) J Stomatol Soc 1963;30:361-385.
13. Parfitt GJ. Measurement of the physiological mobility of individual teeth in an axial direction. J dent Res 1960;39:608-618.
14. Körber KH. Periodontal pulsation. J Periodontol 1970;41:382-390.
15. Körber KH. Electronic registration of tooth movements. Int Dent J 1971;21:466-477.
16. Hofmann M, Diemer R. Die Pulsation des Zahnes. Dtsch Zahnärztl Z 1963;18:1268-1274.
17. Hofmann M, Diemer R. Die physiologische Zahnbewegung. Dtsch Zahnärztl Z 1966;21:707-718.
18. Tanaka B. The influence of occlusal relation on stomato-gnathic system. (in Japanese) J Jpn Prosthodont Soc 1976;19:480-506.
19. Igarashi Y, Ai M, Saito R. Observation of the tooth support dynamics. Part 2. Measurements of tooth mobility and motility. (in Japanese) J Jpn Prosthodont Soc 1981;25:295-303.
20. Kato H. The function of the tooth supporting structures. Part 1. A method of measuring tooth displacement in two dimensions. (in Japanese) J Jpn Prosthodont Soc 1981;25:733-745.
21. Kato H. The function of the tooth supporting structures. Part 2. The dynamics of molars in function and at rest. (in Japanese) J Jpn Prosthodont Soc 1982;26:133-147.
22. Ikeda T. Influence of occlusal overload on tooth sensation and periodontal tissue. (in Japanese, English abstract) J Jpn Prosthodont Soc 1987;31:675-688.
23. Ioi H, Morishita T, Nakata S, et al. Evaluation of physiological tooth movements within clinically normal periodontal tissues by means of periodontal pulsation measurements. J Periodont Res 2002;37:110-117.
24. Ioi H, Nakata S, Nakasima A, et al. Changes in tooth position in humans in relation to arterial blood pressure. Arch Oral Biol 2002;47:219-226.
25. Willi Schulte. The New Periotest® Method. Compend Contin Educ Dent 1988;12:410-417.
26. Nakao K. Occlusal facets and contacts in normal dentition (Intercuspal position). (in Japanese) J Jpn Prosthodont Soc 1970;14:1-21.
27. Kohno S, Sato T, Tabata T. PERIOTEST®-A new measuring instrument of the dynamic periodontal function and the guide to its application. (in Japanese) QE 1987;6:41-49.
28. Gaengler P, Merte K. Effects of force application on periodontal blood circulation. A vital microscopic study in rats. J Periodont Res 1983;18:86-92.
29. Torisu H. Changes of periodontal vasculature and alveolar bone on the occlusal trauma. (in Japanese, English abstract) Kanagawa Shigaku 1989;24:358-383.
30. Okada D, Miura H, Hasegawa S. The investigation of upper and lower posterior teeth in function. The three dimensional tooth displacement. (in Japanese, English abstract) J Jpn Prosthodont Soc 1998;42:279-286.
31. Ishihara H. Influence of occlusal contacts on tooth displacement. (in Japanese, English abstract) J Stomatol Soc 2000;67:310-321.
32. Amarsaikhan B, Miura H, Okada D, et al. Influence of environmental factors on tooth displacement. J Med Dent Sci 2002;49:19-26.
33. Miura H, Furuki Y, Hasegawa S, et al. Distortion of periodontal tissues during biting. Region of the upper posterior teeth. (in Japanese, English abstract) J Jpn Prosthodont Soc 1993;37:1305-1311.
34. Masuda T, Miura H, Kato H, et al. Distortion of periodontal tissue in maxillary molar region during biting. Measurement with quasi three-dimensional method. Dent Jpn 1998;34:54-58.

35. Jacobs R, van Steenberghe D. Comparative evaluation of the oral tactile function by means of teeth or implant prostheses. Clin Oral Implants Res 1991;2:75-80.
36. Keller D, Hammerle CH, Lang NP. Thresholds for tactile sensitivity perceived with dental implants remain unchanged during a healing phase of 3 months. Clin Oral Implants Res 1996;7:48-54.
37. Wada S, Kojo T, Wang YH, et al. Effect of loading on the development of nerve fibers around oral implants in the dog mandible. Clin Oral Implants Res 2001;12:219-224.
38. Ichikawa T, Nouchi A, Shimada K, et al. Neural control of endosseous implant-masseteric reflex in the cat. (in Japanese, English abstract) J Jpn Prosthodont Soc 1993;37:376-390.