Risk indicators for marginal bone resorption around implants in function for at least 4 years: A retrospective longitudinal study.

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Running title: Risk indicators for peri-implant bone resorption

Summary statement of key findings: Poor oral hygiene, longer functional time, poor oral hygiene, loss of occlusal support, location in the maxilla, cement-retained superstructure, and less keratinized mucosa should be considered as risk indicators for bone resorption around implants.

ABSTRACT

Background: Marginal bone stability is considered one of the most important issues in implant dentistry. It is essential to understand how various factors influence bone resorption around implants. The purpose of this retrospective longitudinal study was to identify potential risk indicators associated with marginal bone resorption around implants in function for at least 4 years.

Methods: Several systemic-, intraoral-, implant-related factors were collected. Marginal bone level change (MBLC) was determined by comparing intraoral radiographs taken at baseline (1 year after prosthesis delivery), and at follow-up (over 3 years from baseline). A hierarchical regression analysis using liner mixed-effects models was performed to examine correlations between MBLC and various factors.

Results: Overall, five hundred and fourteen patients with 1535 implants were analyzed. The mean age of the participants was 62.9 years. Mean annual MBLC was 0.048 mm, and mean functional time was 5.96 years. The result showed that the following explanatory variables had significant effects on MBLC: functional time, plaque control record > 20%, Eichner index C1-3, maxilla, cement-retained superstructure and keratinized mucosa width < 2 mm. We did not find statistically significant associations between bone resorption and some variables known as risk factors, such as diabetes, smoking, and history of periodontitis.

Conclusions: Within the limits of this study, longer functional time, poor oral hygiene, loss of occlusal support, location in the maxilla, cement-retained superstructure, and less keratinized mucosa should be considered as risk indicators for bone resorption around implants.

KEYWORDS: Dental Implants, Bone Resorption, Epidemiology, Risk Factors, Longitudinal Studies

INTRODUCTION

Dental implants have become a well-established and reliable treatment for replacing missing teeth.[1] Several studies have provided evidence of the longevity of implant treatment,[2,3] yet various biological complications have also been reported. Peri-implantitis is an inflammatory reaction in the hard and soft tissue with progressive marginal bone resorption around the dental implant.[4] Lee et al.[5] reported in their meta-analysis of 47 studies that implant-based and patient-based peri-implantitis prevalence rates were 9.25% and 19.83%, respectively. Similarly, Derks et al.[6] reported a rate of 22% at the patient level in their review of data from 15 studies with at least 100 patients. On the other hands, Karl et al.[7] reported a rate of 1.36-5.20% at the patient level in their review. Albrektsson et al.[8] also reported that combined rate of peri-implantitis and implant failure at over 10 years of follow-up was less than 5%. The prevalence rates of peri-implantitis were dissimilar because each definition of peri-implantitis was diverse among these published reports.

Subsequent progressive marginal bone resorption around a dental implant has been considered as one of characteristics of peri-implantitis.[4] Thus, marginal bone stability is considered one of the most important issues in implant dentistry. Many studies have shown correlations between a history of periodontitis, smoking, poor oral hygiene and the development of peri-implantitis.[9,10] The associations between various factors such as systemic diseases, implant position, prosthetic design, implant connection types and marginal bone resorption are also being examined.[11-14] Additionally, occlusal overload is considered to be associated with peri-implant bone resorption.[15] This report is supported by finite element studies showing that excessive occlusal stress can concentrate at the implant marginal bone and cause microfracture within the bone.[16,17] However, there is little evidence that occlusal overload alone affects peri-implant bone resorption, because there are many background factors involved.[18] Consequently, it is essential to understand how various factors influence bone resorption around implants. On the other hand, marginal bone resorption during the first year of implant function should be distinguished from late onset bone resorption, because of the ongoing process of bone remodeling.[19] Therefore, the baseline setting is considered to be important for evaluating marginal bone resorption, and to examine the influence of these

various factors, it is required that unified standards that take the normal reaction of peri-implant bone into consideration.

The method of statistical analysis is also an important factor in clearly understanding the risk indicators for peri-implant bone resorption. Many clinical studies collect multiple implant data from the same individual. Implants from the same patient usually have similar properties, each implant should not be considered independent in statistical analysis. However, few studies have investigated the risk indicators for marginal bone resorption using a multi-level regression model which makes it possible to consider multiple variables within the same individual.

The purpose of this retrospective longitudinal study was to identify potential risk indicators associated with marginal bone resorption around implants in function using multi-level regression models.

MATERIALS AND METHODS

Study Design and Participants

This retrospective longitudinal study enrolled Japanese patients treated at a dental university hospital[*] and seven general dental offices[†, ‡, §, ǁ, ¶, #, **] between November 1996 and December

2013. All the implant treatment including the surgery were undergone by dentists who had more than 10 years' experience of implant treatment. This study protocol was approved by the Osaka University Graduate School of Dentistry Ethics Committee (H28-E24). Every clinical investigation was conducted according to the principles expressed in the Helsinki Declaration of 1975, as revised in 2000. This study also followed the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.[20]

Patients included in this study had at least one moderately rough surfaced titanium implant with fixed prosthesis in function over 4 years and intraoral radiographs taken at 1 year after prosthesis delivery. After the purpose of this study was explained, all patients who were willing to take part in the study provided informed written consent. All participants had received periodontal treatment and smoking cessation guidance before implant placement, if necessary. Exclusion criteria in this study were as follows:

- Patients not participating in the regular maintenance programme
- Patients who have received radiotherapy to the head/neck area
- Patients with uncontrolled systemic diseases

Data Collection

All participants received clinical, periodontal and radiographic examinations. Demographic data and treatment histories were collected using direct interviews and dental records. The following data were collected.

Systemic Factors

Age at baseline, sex, smoking habits (smoking at least one cigarette per day was defined as presence of a smoking habit), drinking habits (daily habitual intake of alcohol was defined as presence of a drinking habit), and systemic diseases were recorded.

Intraoral Factors

These included history and presence of periodontitis, oral hygiene status and occlusal support. Periodontitis was defined as when more than two teeth had the following conditions: presence of bleeding on probing / suppuration, attachment loss ≥ 2 mm, and pocket probing depth ≥ 6 mm, according to Derks et al.[21] Oral hygiene status was evaluated based on plaque control record (PCR; O'Leary score),[22] which is widely used in clinical practice. The participants were divided into two groups using the cut-off value of 20%. The number of posterior occlusal contacts of the existing natural teeth were used for classification according

to the Eichner index (Table 1).[23] The participants were classified into Eichner index A1-3, B1-2, B3-4 and C1-3.

Implant-related Factors

Each implant was examined for the following items: functional time, implant length and diameter, jaw position (maxilla or mandible), arch position (anterior or posterior, distal to the canine tooth was considered posterior), surgical procedure (one-stage or two-stage), with or without bone augmentation (guided bone regeneration; GBR, sinus lift and socket lift), fixation method (cement-retained or screw-retained), connection type (external or internal), collar design (tissue-level or bone-level), superstructure design (single crown or splinted crown), keratinized mucosa width (KMW) and implant system (Nobel Biocare[††], Dentsply Sirona[‡‡], ZIMMER BIOMET[§§], GC[‖‖], Straumann[¶¶] and other[##, ***, †††]). KMW was the minimum distance between the gingival margin and the mucogingival junction around the implant. Implants were divided into two groups (KMW < 2 mm or KMW ≥ 2 mm).

Other Factors

Bruxism and gonial angle on the orthopantomogram were included. Bruxism was diagnosed if the following signs presented: subjective symptoms of teeth grinding or clenching,

abnormal tooth wear and transient pain or fatigue of the masseter muscle. Gonial angle was measured on the orthopantomogram as an index of the occlusal force.[24]

Radiographic Evaluation

Bone resorption during the first year of implant function has been reported to be relatively high because of bone remodeling.[19] Therefore, this study evaluated bone resorption at 1 year after delivery of the prosthesis.

Intraoral radiographs of the implant were taken at baseline (1 year after prosthesis delivery), and at follow-up (over 3 years from baseline). One blinded examiner (MW) analyzed the radiographs using image analysis software‡‡‡. The measuring method is presented in Figure 1. The vertical distance between the marginal bone level and the implant apex was measured on the mesial and distal sides of the implant. The actual implant length was used for calibration of the measurements. The difference in the distance between baseline and follow-up was considered as the marginal bone level change (MBLC). The larger MBLC out of the mesial and distal sides was used for analysis. The intra-class correlation coefficient for the MBLC was 0.97, which indicated an almost-perfect concordance.

Statistical Analysis

The mean and standard deviation (SD) for continuous variables and the percentage for categorical variables were presented as descriptive statistics. The Pearson correlation test, polychoric correlation test and polyserial correlation test were conducted to assess the correlations between two continuous variables, two categorical variables and continuous variable and categorical variable, respectively. For patients with multiple implants, each implant was not considered as independent in the statistical analysis, because there is a correlation between implants in the same patient. Therefore, to adjust for correlated variables, linear mixed-effects models (LMM) were applied to identify risk indicators for marginal bone resorption. The MBLC in each implant was taken as an objective variable in the models. To adjust for correlations with multiple implants in the same patient, and patients clustered in the same clinician, the parameter “patient” and “clinician” were used as random effects in the LMM.

To perform a hierarchical regression analysis, we gradually added variables from higher risk factors based on past reports, and constructed four models (Model 1 to 4). The explanatory variables were input to each model according to the following steps. The first model (Model 1) included demographic information: age, sex and functional time. In the second model (Model 2), the following items known as the risk factors for peri-implant bone

resorption were added: PCR, diabetes, smoking habits and history of periodontitis.[9,10,12,25] In the following step (Model 3), the relevant variables of osteoporosis, Eichner index, bruxism, jaw position, surgical procedure, GBR, fixation method, connection type, KMW, and superstructure design were added. The final model (Model 4) included all variables. We used full information maximum-likelihood estimations for all LMM analyses to compare models. The Akaike's information criterion (AIC) and likelihood ratio test were used for model comparison. The AIC is widely used for measuring the validity of a statistical model. The model with the lower AIC indicates a better statistical fit.

All statistical analyses were performed using R version 3.31[§§§]. For the computation of linear mixed models, we used the "polycor" and "lme4" packages in R. The level of statistical significance was set to 0.05 for all analyses.

RESULTS

Of the 559 patients recruited for this study, we excluded those with missing data. Finally, five hundred and fourteen patients (333 females, 181 males) treated with 1535 implants were analyzed (see supplementary Figure 1 in online *Journal of Periodontology*). Description of

all the variables for the patients and implants are presented in Tables 2 and 3. The mean age of the participants was 62.9 years (SD = 10.6). Mean annual MBLC was 0.048 mm (SD = 0.146), and mean functional time was 5.96 years (SD = 2.48). There were strong correlation (correlation coefficient > 0.7) between the history of periodontitis and presence of periodontitis, connection type and collar design, respectively. In consideration of multicollinearity, presence of periodontitis and collar design were excluded from explanatory variables of multivariate analysis.

Tables 4 and 5 show the results of the hierarchical regression analysis. Unstandardized regression coefficients (B), 95% confidence intervals (CI) and *P*-values estimated by LMM analyses in Models 1 to 4 are presented (Table 4). The model comparison revealed that the variables added in Model 4 did not improve the AIC value and were not significant variables (Table 5). Therefore, Model 3, which showed the lowest AIC value, was chosen as the final model for estimation, and the likelihood ratio test supported this conclusion.

Model 3 showed that the following explanatory variables had significant effects on bone resorption: functional time (B = 0.04, 95% CI: 0.02–0.06), PCR > 20% (B = 0.12, 95% CI: 0.01–0.22), Eichner index C1-3 (B = 0.39, 95% CI: 0.14–0.61), maxilla (B = 0.11, 95%

CI: 0.03–0.19), cement-retained superstructure (B = 0.13, 95% CI: 0.02–0.25) and KMW < 2 mm (B = 0.14, 95% CI: 0.06–0.22). The coefficient in the continuous variable shows the amount of the MBLC if the variable is changed by one unit after holding other explanatory variables constant. Similarly, the coefficient in the categorical variable indicates the MBLC difference between groups after adjusting other variables.

DISCUSSION

The present retrospective longitudinal study evaluated bone resorption around implants after 1 year of loading using hierarchical regression analysis with multi-level models. To examine the influence of various clinical factors, a large number of implants were investigated based on a unified standard in this multicenter study. Functional time, oral hygiene status, occlusal support, implant position, prosthetic design and KMW were found to be significantly associated with bone resorption.

Generally, bone resorption occurs continuously during function. Karl et al.[7] reported that mean annual MBLC was 0.18 mm at the implant level after 1 year of function. In our study, mean annual MBLC was 0.048 mm. This result indicates a lower level of bone

resorption. A key reason for this may be that all participants participated in a regular maintenance program which seems to be effective in reducing the risk of peri-implant bone resorption.[26] The program could also be responsible for the fact that few participants showed extremely poor PCR scores. Nevertheless, the PCR > 20% group showed significantly higher MBLC compared with the PCR ≤ 20% group in this study. Oral hygiene status is known to be a principal factor in the etiology of peri-implant disease,[10,27] and persistent inflammation caused by plaque accumulation around implants will result in bone resorption.

Keratinized mucosa is known to improve resistance to mechanical and biological stimulation.[28] A recent clinical study showed that implant sites without keratinized mucosa (less than 2 mm) tended to result in more brushing discomfort, plaque accumulation, and peri-implant soft tissue inflammation than those sites with sufficiently keratinized mucosa.[29] In this study, we found that the presence of keratinized mucosa was necessary to prevent marginal bone resorption. Bone density is also thought to be an important factor affecting implant stability and successful implantation.[30] The maxilla has lower bone density than the mandible.[31,32] Bone resorption was significantly higher around maxillary implants than mandibular implants in this study, which is thought to be related to this anatomical feature. Our results also confirmed that the MBLC in cement-retained superstructures was higher than

that in screw-retained superstructures. The advantages of cement-retained superstructures include the simplicity of clinical and laboratory procedures, the elimination of unaesthetic screw access holes, and easier control of the occlusion; however, there is evidence that excess cement exists frequently in cement-retained superstructures, causing soft tissue inflammation and bone resorption.[33]

Interestingly, the group C of the Eichner index, which has no occlusal support from the natural teeth, is associated with bone resorption. A possible reason for this is that the rate of occlusal force applied to the implant may increase because of the loss of occlusal support from the natural teeth, assuming the occlusal force is constant. In addition, Higaki et al.[34] investigated the difference in sensation between dental implants and natural teeth, and found that implants have significantly higher thresholds of tactile sensibility and thickness discrimination than natural teeth. It is well understood that the proprioceptive feedback of the periodontal ligament plays an essential role in modulating complex mandibular movements and the masticatory protective reflex.[35,36] In other words, loss of occlusal contacts between natural teeth may cause accommodative disorder of occlusal force. Taking into consideration the factors mentioned above, it is suggested that loss of occlusion support affects bone resorption by causing occlusal overload. However, the alveolar ridge of these participants is

often severely resorbed as a result of early teeth extractions. Canullo et al.[37] reported that the limited positions available for implant insertion may cause tridimensional malposition related to bone resorption around the implant. Therefore, it is considered that more detailed analysis of the relationship between occlusal support and bone resorption is necessary.

Additionally, there is the evidence of clinician's technique being associated with marginal bone loss.[38] In this study, we devised following two things for this point. Only dentists with more than 10 years' experience of implant treatment participated in this study. Furthermore, by setting "clinician" to random effect in linear mixed-effects models, we performed statistical analysis with consideration of differences between clinicians.

We did not find statistically significant associations between bone resorption and some variables known as risk factors, such as diabetes, smoking, and history of periodontitis.[9,10,12,25] It has been reported that implant treatment for patients with well-controlled diabetes can be acceptable.[39] The participants with uncontrolled systemic diseases were excluded in this study, so it is possible that the influence of diabetes could not be detected. Pre-operative periodontal treatment and smoking cessation guidance were also performed thoroughly in this study. Even participants with a history of periodontitis did not show a difference in the MBLC, probably because their periodontal condition was relatively

controlled. In addition, Abduljabbar et al.[40] reported that there was no significant difference in marginal bone resorption between smokers and non-smokers under well-controlled oral hygiene. Also in this study, bone resorption tended to be higher in smokers compared with non-smokers, but this difference was not significant. The other reason for this finding may be that there were only a few smokers among the participants (under 10%), and none of them were heavy smokers. At the same time, using smaller cutoff value (one cigarette per day) than many other studies requires interpretation of the results with due consideration.

There are several limitations in this study. Firstly, this study is not a randomized controlled trial, and can therefore not evaluate treatment interventions, because it was difficult to collect and evaluate all clinical parameters due to this retrospective study. Only participants who satisfied the inclusion criteria were targeted in this study, which may have resulted in selection bias. Further bias may have resulted from treatment planning by the dentist. Therefore, this study can reveal only relation not causal relationship between the factors and the marginal bone resorption. The MBLC was measured in intraoral radiographs and adjusted using the actual implant length in this study. A limitation of this measuring method is that only the mesiodistal bone level of the implant can be evaluated, and the buccolingual bone cannot be observed. Measurement by computerized tomography would be

preferable; however, from the viewpoint of exposure dose, it is not practical to take regular computerized tomograms for all patients. Finally, we analyzed the MBLC using a linear regression model. However, it has been reported that bone resorption progresses acceleratively.[41] For a more detailed investigation, it may be necessary to perform a non-linear regression analysis using measured values at multiple points in time. Despite the limitations outlined above, the findings of this large-scale epidemiological study of rough surface implants are of clinical importance.

CONCLUSIONS

Within the limits of this study, poor oral hygiene, loss of occlusal support, location in the maxilla, cement-retained superstructure, less keratinized mucosa, and longer functional time should be considered as risk indicators for bone resorption around implants.

FOOTNOTES

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REFERENCES

1. Esposito M, Grusovin MG, Coulthard P, Thomsen P, Worthington HV. A 5-year follow-up comparative analysis of the efficacy of various osseointegrated dental implant systems: a systematic review of randomized controlled clinical trials. *Int J Oral Maxillofac Implants* 2005;20:557-568.

2. Jimbo R, Albrektsson T. Long-term clinical success of minimally and moderately rough oral implants: a review of 71 studies with 5 years or more of follow-up. *Implant Dent* 2015;24:62-69.

3. Chrcanovic BR, Kisch J, Albrektsson T, Wennerberg A. A retrospective study on clinical and radiological outcomes of oral implants in patients followed up for a minimum of 20 years. *Clin Implant Dent Relat Res* 2018;20:199-207.

4. Berglundh T, Armitage G, Araujo MG et al. Peri-implant diseases and conditions: Consensus report of workgroup 4 of the 2017 world workshop on the classification of

periodontal and peri-implant diseases and conditions. *J Clin Periodontol* 2018;45 Suppl 20:S286-S291.

5. Lee CT, Huang YW, Zhu L, Weltman R. Prevalences of peri-implantitis and peri-implant mucositis: systematic review and meta-analysis. *J Dent* 2017;62:1-12.

6. Derks J, Tomasi C. Peri-implant health and disease. A systematic review of current epidemiology. *J Clin Periodontol* 2015;42 Suppl 16:158S-171S.

7. Karl M, Albrektsson T. Clinical performance of dental implants with a moderately rough (TiUnite) surface: A meta-analysis of prospective clinical studies. *Int J Oral Maxillofac Implants* 2017;32:717-734.

8. Albrektsson T, Buser D, Chen ST et al. Statements from the Estepona consensus meeting on peri-implantitis, February 2-4, 2012. *Clin Implant Dent Relat Re*s 2012;14:781-782.

9. Heitz-Mayfield LJ. Peri-implant diseases: diagnosis and risk indicators. *J Clin Periodontol* 2008;35 Suppl 8:292-304.

10. Renvert S, Quirynen M. Risk indicators for peri-implantitis. A narrative review. *Clin Oral Implants Res* 2015;26 Suppl 11:15-44.

11. Choi YG, Eckert SE, Kang KL, Shin SW, Kim YK. Epidemiology of implant mortality disparity among intraoral positions and prosthesis types. *Int J Oral Maxillofac Implants* 2017;32:525-532.

12. Monje A, Catena A, Borgnakke WS. Association between diabetes mellitus/hyperglycaemia and peri- implant diseases: Systematic review and meta-analysis. *J Clin Periodontol* 2017;44:636-648.

13. de Medeiros FCFL, Kudo GAH, Leme BG, et al. Dental implants in patients with osteoporosis: a systematic review with meta-analysis. *Int J Oral Maxillofac Surg* 2018;47:480-491.

14. Lemos CAA, Verri FR, Bonfante EA, Santiago Júnior JF, Pellizzer EP. Comparison of external and internal implant-abutment connections for implant supported prostheses. A systematic review and meta-analysis. *J Dent* 2018;70:14-22.

15. American Academy of Periodontology. Peri-implant mucositis and peri-implantitis: a current understanding of their diagnoses and clinical implications. *J Periodontol* 2013;84:436-443.

16. Hudieb MI, Wakabayashi N, Kasugai S. Magnitude and direction of mechanical stress at the osseointegrated interface of the microthread implant. *J Periodontol* 2011;82:1061-1070.

17. Rungsiyakull C, Rungsiyakull P, Li Q, Li W, Swain M. Effects of occlusal inclination and loading on mandibular bone remodeling: A finite element study. *Int J Oral Maxillofac Implants* 2011;26:527-537.

18. Naert I, Duyck J, Vandamme K. Occlusal overload and bone/implant loss. *Clin Oral Implants Res* 2012;23 Suppl 6:95-107.

19. Albrektsson T, Chrcanovic B, Östman PO, Sennerby L. Initial and long-term crestal bone responses to modern dental implants. *Periodontol 2000* 2017;73:41-50.

20. von Elm E, Altman DG, Egger M et al. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. *International Journal of Surgery* 2014;12:1495-1499.

21. Derks J, Schaller D, Håkansson J, Wennström JL, Tomasi C, Berglundh T. Effectiveness of Implant Therapy Analyzed in a Swedish Population: Prevalence of Peri-implantitis. *J Dent Res* 2016;95:43-49.

22. O'Leary TJ, Drake RB, Naylor JE. The plaque control record. *J Periodontol* 1972;43:38.

23. Eichner K. A group classification of edentulous arches for prosthetics. *Dtsch Zahnarztl Z* 1955;10:1831-1834. (in German)

24. Miwa S, Wada M, Murakami S, Suganami T, Ikebe K, Maeda Y. Gonial angle measured by orthopantomography as a predictor of maximum occlusal force. *J Prosthodont* 2019;28:e426-e430.

25. Ramanauskaite A, Baseviciene N, Wang HL, Tözüm TF. Effect of history of periodontitis on implant success: meta-analysis and systematic review. *Implant Dent* 2014;23:687-696.

26. Aguirre-Zorzano LA, Vallejo-Aisa FJ, Estefanía-Fresco R. Supportive periodontal therapy and periodontal biotype as prognostic factors in implants placed in patients with a history of periodontitis. *Medicina oral, patologia oral y cirugia bucal* 2013;18:e786-792.

27. Rokn A, Aslroosta H, Akbari S, Najafi H, Zayeri F, Hashemi K. Prevalence of peri-implantitis in patients not participating in well-designed supportive periodontal treatments: a cross-sectional study. *Clin Oral Implants Res* 2017;28:314-319.

28. Pranskunas M, Poskevicius L, Juodzbalys G, Kubilius R, Jimbo R. Influence of peri-implant soft tissue condition and plaque accumulation on peri-implantitis a systematic review. *J Oral Maxillofac Res* 2016;7:e2.

29. Souza AB, Tormena M, Matarazzo F, Araújo MG. The influence of peri-implant keratinized mucosa on brushing discomfort and peri-implant tissue health. *Clin Oral Implants Res* 2016;27:650-655.

30. Javed F, Ahmed HB, Crespi R, Romanos GE. Role of primary stability for successful osseointegration of dental implants: Factors of influence and evaluation. *Interv Med Appl Sci* 2013;5:162-167.

31. Fuh LJ, Huang HL, Chen CS, et al. Variations in bone density at dental implant sites in different regions of the jawbone. *J Oral Rehabil* 2010;37:346-351.

32. Hao Y, Zhao W, Wang Y, Yu J, Zou D. Assessments of jaw bone density at implant sites using 3D cone-beam computed tomogra phy. *Eur Rev Med Pharmacol Sci* 2014;18:1398-1403.

33. Korsch M, Robra BP, Walther W. Cement-associated signs of inflammation: retrospective analysis of the effect of excess cement on peri-implant tissue. *Int J Prosthodont* 2015;28:11-18.

34. Higaki N, Goto T, Ishida Y, Watanabe M, Tomotake Y, Ichikawa T. Do sensation differences exist between dental implants and natural teeth?: a meta-analysis. *Clin Oral Implants Res* 2014;25:1307-1310.

35. Jacobs R, van Steenberghe D. Role of periodontal ligament receptors in the tactile function of teeth a review. *J Periodontal Res* 1994;29:153-167.

36. Trulsson M. Sensory-motor function of human periodontal mechanoreceptors. *J Oral Rehabil.* 2006;33:262-273.

37. Canullo L, Tallarico M, Radovanovic S, Delibasic B, Covani U, Rakic M. Distinguishing predictive profiles for patient-based risk assessment and diagnostics of plaque induced, surgically and prosthetically triggered peri-implantitis. *Clin Oral Implants Res* 2016;27:1243-1250.

38. Qian J, Wennerberg A, Albrektsson T. Reasons for marginal bone loss around oral implants. *Clin Implant Dent Relat Res* 2012;14:792-807.

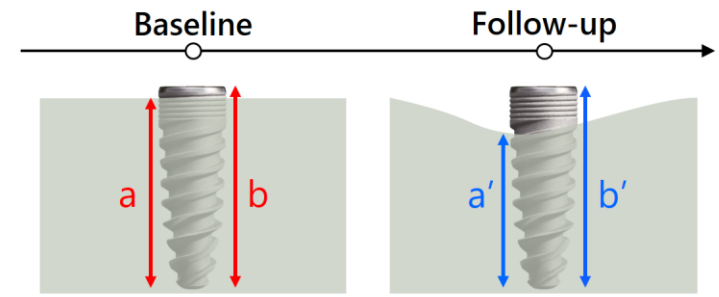
39. Gómez-Moreno G, Aguilar-Salvatierra A, Rubio Roldán J, Guardia J, Gargallo J, Calvo-Guirado JL. Peri-implant evaluation in type 2 diabetes mellitus patients: a 3-year study. *Clin Oral Implants Res* 2015;26:1031-1035.

40. Abduljabbar T, Al-Hamoudi N, Al-Sowygh ZH, Alajmi M, Javed F, Vohra F. Comparison of peri-implant clinical and radiographic status around short (6 mm in length) dental implants placed in cigarette-smokers and never-smokers: Six-year follow-up results. *Clin Implant Dent Relat Res* 2018;20:21-25.

41. Derks J, Schaller D, Håkansson J, Wennström JL, Tomasi C, Berglundh T. Peri-implantitis - onset and pattern of progression. *J Clin Periodontol* 2016;43:383-388.

Figure legends:

Figure 1. The measuring method for marginal bone level change (MBLC) on the intraoral radiographs. The vertical distance between the marginal bone level and the implant apex (a) was measured. The actual implant length (b) was used for calibration of the measurements.



$$\text{MBLC} = \left(a \times \frac{\text{Implant length}}{b}\right) - \left(a' \times \frac{\text{Implant length}}{b'}\right)$$

Tables:

Table 1. Eichner index

Group A: Occlusal contacts are present in all four OSZs
A1: No missing teeth in the mandible and maxilla
A2: At least one missing tooth in either the mandible or maxilla
A3: At least one missing tooth in both the mandible and maxilla
Group B: Occlusal contacts are present in three to one OSZ(s) or in the anterior region only.
B1: Occlusal contacts are present in three OSZs
B2: Occlusal contacts are present in two OSZs
B3: Occlusal contacts are present in one OSZ
B4: Occlusal contact(s) in the anterior region only
Group C: No occlusal contact at all.

C1: At least one tooth in both the mandible and maxilla without any occlusal contact

C2: At least one tooth in either the mandible or maxilla

C3: Fully edentulous in both arches

Antagonistic occlusal contacts of the existing natural teeth or fixed prosthesis using residual natural teeth in the premolar and molar regions are evaluated by Eichner index as occlusal support zones (OSZs).

Table 2. Description of patients

Categorical variables	n	%
Sex		
Female	333	64.8
Male	181	35.2
Smoking habits		
Yes	50	9.7
No	464	90.3
Drinking habits		
Yes	143	27.8
No	371	72.2
Systemic diseases		

Diabetes	28	5.4
Hypertension	70	13.6
Hyperlipidemia	30	5.8
Osteoporosis	12	2.3
Other	14	2.7
History of periodontitis		
Yes	233	45.3
No	281	54.7
Presence of periodontitis		
Yes	148	28.8
No	366	71.2
Plaque control record		
> 20%	232	45.1
≤ 20%	282	54.9
Eichner index		
A1-3	174	33.8
B1-2	241	46.9
B3-4	73	14.2
C1-3	26	5.1
Bruxism		

Yes	280	54.5
No	234	45.5
Total	514	100.0

Continuous variables	mean	SD
Age	62.9	10.6
Gonial angle	124.9	25.3
Number of implants	3.0	2.4

SD, standard deviation

Table 3. Description of implants

Categorical variables	n	%
Implant position		
Upper-anterior	141	9.2
Upper-premolar	231	15.0
Upper-molar	297	19.3
Lower-anterior	49	3.2
Lower-premolar	222	14.5
Lower-molar	595	38.8

Surgical procedure		
One-stage	663	43.2
Two-stage	872	56.8
Bone augmentation		
GBR	111	7.2
Socket lift	39	2.5
Sinus lift	67	4.4
Fixation method		
Cement	1119	72.9
Screw	416	27.1
Connection type		
External	810	52.8
Internal	725	47.2
Collar design		
Bone-level	1513	98.6
Tissue-level	22	1.4
Superstructure design		
Single crown	310	20.2
Splinted crown	1225	79.8
Keratinized mucosa width		

< 2 mm	540	35.2
≥ 2 mm	995	64.8
Implant brand		
Nobel Biocare	608	39.6
Dentsply Sirona	594	38.7
ZIMMER BIOMET	154	10.0
GC	108	7.0
Straumann	56	3.6
Other	15	1.0
Total	1535	100.0

Continuous variables	mean	SD
Diameter (mm)	4.07	0.47
Length (mm)	11.1	1.88
Functional time (year)	5.96	2.48
Annual MBLC (mm)	0.048	0.146

GBR, guided bone regeneration

SD, standard deviation

MBLC, marginal bone level change

Table 4. Hierarchical multiple regression models by using linear mixed-effects models predicting marginal bone level change

Variable	Model 1			Model 2			Model 3			Model 4		
	B	95% CI		B	95% CI		B	95% CI		B	95% CI	
Age[§]	0.03	-0.02	0.07	0.03	-0.02	0.07	-0.01	-0.06	0.03	-0.01	-0.06	0.04
Sex[‖]	0.08	-0.02	0.20	0.01	-0.10	0.12	0.02	-0.10	0.13	0.03	-0.09	0.14
Functional time[¶]	**0.03**	* **0.01**	**0.06**	**0.04**	* **0.02**	**0.06**	**0.04**	* **0.02**	**0.06**	**0.03**	* **0.01**	**0.05**
PCR[#]				**0.13**	† **0.02**	**0.24**	**0.12**	† **0.01**	**0.22**	**0.12**	† **0.03**	**0.23**
Diabetes[**]				0.09	-0.14	0.30	0.08	-0.13	0.27	0.11	-0.10	0.32
Smoking habits[**]				**0.22**	† **0.06**	**0.40**	0.15	‡ -0.01	0.34	0.17	‡ -0.01	0.34
History of				0.00	-0.11	0.11	0.00	-0.10	0.10	-0.00	-0.11	0.10

periodontitis**	2	0	3	01	9	2	1	2	9			
Osteoporosis**				0.06	-0.28	-	0.37	0.06	-0.25	-	0.38	
Eichner index†† (1: B1-2)				0.08	-0.06	-	0.22	0.09	-0.04	-	0.23	
(1: B3-4)				0.08	-0.09	-	0.25	0.07	-0.10	-	0.25	
(1: C1-3)				**0.39**	* **0.14**	-	**0.61**	**0.40**	* **0.17**	-	**0.66**	
Bruxism**				0.05	-0.05	-	0.15	0.04	-0.07	-	0.14	
Jaw position‡‡				**0.11**	* **0.03**	-	**0.19**	0.06	-0.02	-	0.15	
GBR**				0.02	-0.12	-	0.18	0.02	-0.13	-	0.17	
Fixation method§§				**0.13**	† **0.02**	-	**0.25**	**0.13**	† **0.01**	-	**0.24**	

Connection type[‖]	0.10		-0.03	-	0.20	0.02		-0.20	-	0.22
KMW[¶¶]	**0.14**	*	**0.06**	-	**0.22**	**0.16**	*	**0.08**	-	**0.25**
Superstructure design[##]	0.10	‡	-0.01	-	0.20	0.10	‡	-0.01	-	0.20
Drinking habits[**]						-0.01		-0.14	-	0.12
Hypertension[**]						-0.07		-0.22	-	0.07
Hyperlipidemia[**]						-0.03		-0.24	-	0.18
Gonial angle[***]						0.01		-0.01	-	0.02
Surgical procedure[†††]						-0.01		-0.11	-	0.09
Arch position[‡‡‡]						-0.00		-0.01	-	0.01

	1	3	0
Implant diameter§§§	-0.03	-0.1	0.05
Implant length§§§	0.001	-0.01	0.013
Sinus lift**	0.018	-0.05	0.037
Socket lift**	0.014	-0.10	0.037
Implant brand‖‖ (1: Dentsply Sirona)	-0.03	-0.28	0.188
(1: ZIMMER BIOMET)	0.004	-0.14	0.022
(1: GC)	-0.15	-0.40	0.101
(1: Straumann)	-0.21	-0.51	0.101

(1: other)	1	-0.4	-0.4	0.43

B, unstandardized regression coefficient; CI, confidence interval; PCR, plaque control record; GBR, guided bone regeneration; KMW, keratinized mucosa width.

* $P < 0.01$, † $P < 0.05$, ‡ $P < 0.1$. Bold values indicate significance at $P < 0.05$.

§ (per 10 years), ‖ (0: female, 1: male), ¶ (per 1 year), # (0: ≤ 20%, 1: > 20%), ** (0: no, 1: yes), †† (0: A1-3), ‡‡ (0: mandible, 1: maxilla), §§ (0: screw, 1: cement),

‖‖ (0: internal, 1: external), ¶¶ (0: ≥2 mm, 1: <2 mm), ## (0: single, 1: splinting), *** (per 10 degrees), ††† (0: one-stage, 1: two-stage), ‡‡‡ (0: posterior, 1: anterior),

§§§ (mm), ‖‖‖ (0: Nobel Biocare)

Table 5. Results of the model comparison using AIC and likelihood ratio test

	AIC	Deviance	Δdeviance	Df	ΔDf	*P*-value*
Model 1	3147.0	3133.0	Ref	7	Ref	Ref
Model 2	3137.6	3111.6	21.4	13	6	<0.01
Model 3	**3118.6**	**3070.6**	**41.0**	**24**	**11**	**<0.01**
Model 4	3136.7	3060.7	9.8	38	14	0.78

AIC, Akaike's information criterion; Df, degrees of freedom; Ref, reference.

*Likelihood ratio test

The best fitting model using AIC is the Model 3 shown in bold.