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ORIGINAL ARTICLE

Occlusal change in posterior implant-supported single crowns and its association with peri-implant bone level: a 5-year prospective study

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Abstract

Objectives This study aims to analyze the 5-year occlusal change in posterior implant-supported single crowns and the association between the relative occlusal force (ROF) and peri-implant bone level.

Materials and methods Partially edentulous patients who had received implant-supported single crowns in the posterior region were included. Occlusal examinations with a computerized occlusion analysis system were conducted at 0.5, 3, 6, 12, 24, 36, 48, and 60 months after delivery of the implant-supported single crown. The ROFs of implant-supported single crowns, mesial adjacent teeth, and control natural teeth were recorded. Intraoral periapical radiographs were taken at each follow-up time to evaluate marginal bone level (MBL). Ordinary least square regression was used to analyze the association between ROF and MBL.

Results Thirty-seven posterior implant-supported single crowns in 33 participants (23.9 to 70.0 years) were followed up for 0.5 to 60 months [(42.4 ± 26.0) months]. The ROF of implant-supported single crowns increased from 2 weeks to 3 months ($P < 0.01$) and increased continuously between all two sequential time points from 6 to 36 months, with significant differences ($P < 0.05$). Then ROFs of implant-supported single crowns were significantly higher than those of control teeth at 48 and 60 months ($P < 0.05$). Regression analysis showed that ROF was significantly associated with MBL with a coefficient of 0.008 ($P < 0.05$).

Conclusion The ROFs of posterior implant-supported single crown have significant change during 5 years' follow-up. The association between ROF and MBL has limited clinical significance.

Trial registration Chinese Clinical Trial Registry: ChiCTR-ROC-17012240.

Clinical relevance The occlusion of implant-supported single crowns should be carefully monitored during follow-up examinations, and occlusal adjustment should be considered to prevent overloading.

Keywords Dental implant · Single crown · Implant-supported prosthesis · Occlusion · Occlusal force · Marginal bone level

Introduction

Osseointegrated implants react biomechanically to occlusal force in a manner distinct from natural teeth because of the absence of the periodontal ligament and higher threshold of tactile perception [1, 2]. Consequently, dental implants can be prone to occlusal overloading, which might affect the weakest part of the system, producing mechanical complications such as screw loosening, prosthesis failure, and the fracture of screws, veneering material, or even the implant, eventually compromising implant longevity [3–5]. Thus, control and maintenance of occlusion is important as one of the key factors determining the longevity of implant-supported fixed prostheses [6, 7].

To reduce occlusal overload, light contacts at heavy bite and no contact at light bite in maximum intercuspal position

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(MIP) are considered a reasonable approach to distribute the occlusal force on teeth and implants [4, 5]. An occlusal clearance of 10–30 μm was recommended to be left between the occlusal surface of the implant-supported single crown and the opposing teeth [8, 9]. However, previous studies [10, 11] have reported that the occlusal contact of implant-supported single crowns would not remain light with use. Natural dentition may exhibit continued tooth eruption and movement due to occlusal abrasion, periodontal disease, temporomandibular diseases, or orthodontic treatment, which all can cause changes in occlusal force distribution and occlusal contacts [12, 13]. While implants maintain their position integrating with bone under the change of natural teeth, therefore, the occlusion of implant-supported fixed partial prostheses could change over time.

Current scientific evidences as to longitudinal occlusal variation of implant-supported prostheses are mainly cross-section studies or prospective studies with a short-term follow-up [10, 11, 14]. Long-term variation pattern of occlusion of implant-supported single crowns and whether the longitudinal occlusal variation associates with peri-implant bone loss is still unclear.

Therefore, the purpose of this clinical study was to describe and analyze a 5-year longitudinal variation of the relative occlusal force (ROF) and its association with marginal bone level (MBL), in posterior implant-supported single crowns with a computerized occlusion analysis system. The research hypothesis was that the ROF of posterior implant-supported single crowns would change with time.

Materials and methods

Patients and study design

This study was a prospective case series with self-control design, registered in the Chinese Clinical Trial Registry (ChiCTR-ROC-17012240). This study was performed in line with the principles of the Declaration of Helsinki. Ethics approval was granted by the Biomedical Institutional Review Board of Peking University School of Stomatology (No. PKUSSIRB-201310062). Participants were consecutively recruited from partially edentulous patients who received implant-supported single crowns in the posterior region. Written informed consent was obtained from all participants prior to their inclusion in the study. All surgical and restorative phases were performed by dentists at the Department of Prosthodontics, Peking University School and Hospital of Stomatology, Beijing, China, between December 2012 and December 2013. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement was used as the guideline for this study.

Patients were included if the following criteria were satisfied: aged over 20 years; absence of uncontrolled or untreated periodontal disease; had posterior implant-supported single crowns opposed by natural teeth; and exhibited light contacts at heavy bite evaluated with 30-μm articulating paper and no contact at light bite evaluated with 8-μm articulating film in MIP.

Patients were excluded if they were experiencing pain in the temporomandibular joint; had failed to exhibit a stable occlusal relationship (premature contact and/or occlusal interference); and had parafunctional habits (clenching and/or bruxism) detected by inquiry and examination. In order to control the confounding factors that could change the occlusion distribution of the entire dentition, patients were dropped out if they had undergone any therapy involving occlusal adjustments, composite resin restorations, crown restorations, orthodontics, or tooth extraction after delivery of the implant-supported single crown, or if mechanical complications relating to occlusion of the prosthesis occurred, such as chipping on the occlusal surface, screw loosening or loss of retention, and the prosthesis had to be remade. Then only the data prior to the occurrence of dropping out were included.

The primary outcome variable was the change of the ROFs at different follow-up time, especially in the first 3 months. To maintain a significance level of 0.025 and power of 80% to detect a difference of 5% in the mean changes of the ROFs between 2 weeks and 3 months, with a common standard deviation of 2.8%, a minimum of 12 patients had to be enrolled, while 16 patients (30% more) should be included to compensate for possible dropouts.

The prostheses were screw- or cement-retained and included metal-ceramic crowns, metal-resin crowns, and cast metal crowns delivered 4 to 5 months after implant placement. The metal was noble metal alloy. No occlusal contact was detected on the composite resin used to seal the screw access hole of screw-retained prostheses. The corresponding tooth on the contralateral side of the arch was chosen as control tooth. If the contralateral tooth was missing, an adjacent tooth with similar occlusal surface area to the implant-supported single crown was chosen. The occlusion of the mesial adjacent teeth, as a part of partial occlusion variation, was also evaluated. Clinical information, namely age, gender, smoking habit, implant system, retention method, and superstructure material of implant-supported single crowns, were collected. Patients who did not smoke during the evaluation period were regarded as nonsmokers irrespective of their smoking history.

Digital occlusion analysis

At 0.5, 3, 6, 12, 24, 36, 48, and 60 months after prosthesis delivery, the analysis of occlusion was performed with a computerized occlusion analysis system (T-Scan III®, Tekscan, USA). Based on the literatures [15, 16] and T-scan system user manual, the ROF of each tooth was defined as the percentage against the total occlusal force of the entire dentition at the current timeline position, which is MIP in this study. Before the examination, the participants were asked to sit in a relaxed upright position in the dental chair and taught to clench their teeth in MIP. According to the manufacturer's recommendation, the sensitivity level of the system was calibrated to match the range of occlusal force in each individual before recording. The participants were then instructed to clench firmly on the sensor for 3 times, and a video was recorded by the computer for analysis. The occlusal contacts in the system were verified with 100-µm articulating paper (Fig. 1).

The following occlusion parameters were evaluated in this study: computer-generated ROFs (expressed as a percentage) of implant-supported single crowns, mesial adjacent teeth, and control teeth at the MIP; occlusion time (OT), which was defined as the time from the first occlusal contact to the MIP and automatically calculated by the computerized occlusion analysis system, as measured from the first tooth contact until the last tooth contact was attained; the implant-supported prosthesis occlusion time (IOT), which was defined as the time from the first occlusal contact of implant-supported single crown to the MIP and calculated according to the recorded video (Fig. 2); and the IOT:OT ratio, which showed the relative occlusal time of implant-supported single crowns. MIP was determined by the computerized occlusion analysis system at the frame where maximum intercuspation occurred, or the largest area of tooth contact. All values were calculated as the mean values of the three repeated recordings.

Radiographic examination

To evaluate MBL, intraoral periapical radiographs were taken at each follow-up time, with a digital radiograph machine (Soredex Minray, Finland) using a standardized film holder. To control interobserver variability, a single observer (Q.D.) who was blinded to patient information evaluated all radiographs in a random order. The distal and mesial MBL, defined as the distance from the implant shoulder to the first bone-to-implant contact, was measured in millimeters using a software program (Image J, Bethesda, MD, USA). The known distance of implant length was used for calibration. Mesial and distal bone level measurements were averaged per implant (Fig. 3). All radiographic measurements were performed twice with an intermeasuring period of 2 weeks. These two measurements for MBL were expressed by MBL1 and MBL2 as dependent variables. Cohen's kappa coefficient was calculated to assess the agreement between the two measurements.

Statistical analysis

Statistical analysis was performed with statistical software (IBM SPSS Statistics v18.0, Chicago, IL, USA). Descriptive statistical methods were used to assess data related to ROFs, IOT:OT ratio, and MBL. If the assumption of normality was justified, the value was expressed as mean ± standard deviation. And the paired *t* test was used to compare the IOT:OT ratios and ROFs of the same implant-supported single crowns at 2 different time points as a before-after control and the differences in ROFs between the implant-supported single crowns and control teeth of the same patient at the same time point as a self-control. If not, the values were expressed by the median (lower and quartiles) and analyzed by Wilcoxon signed-rank test.

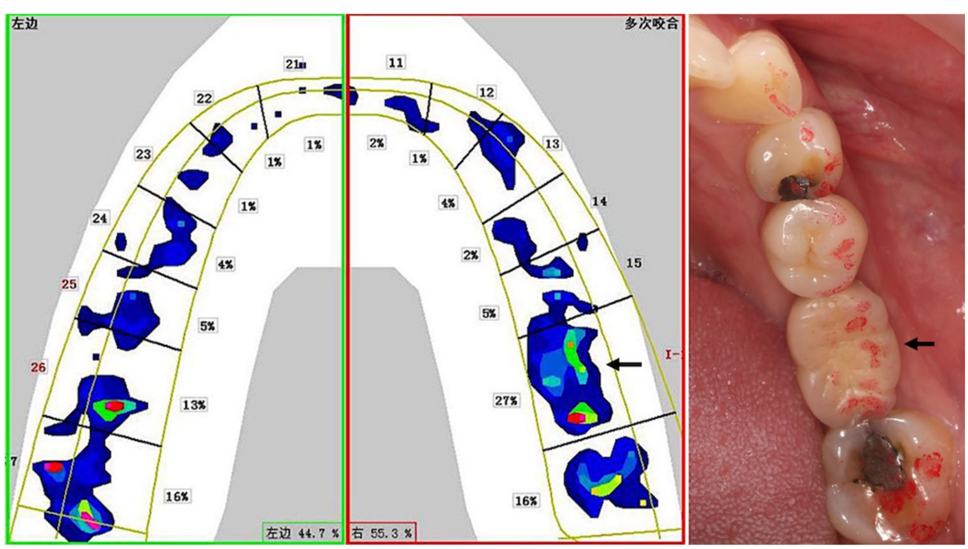

Fig. 1 T-scan occlusal examination (left) and occlusal contact marked using 100-µm articulating paper (right) in maximum intercuspal position at 5-year follow-up. The black arrow marks the position of implant-supported single crown

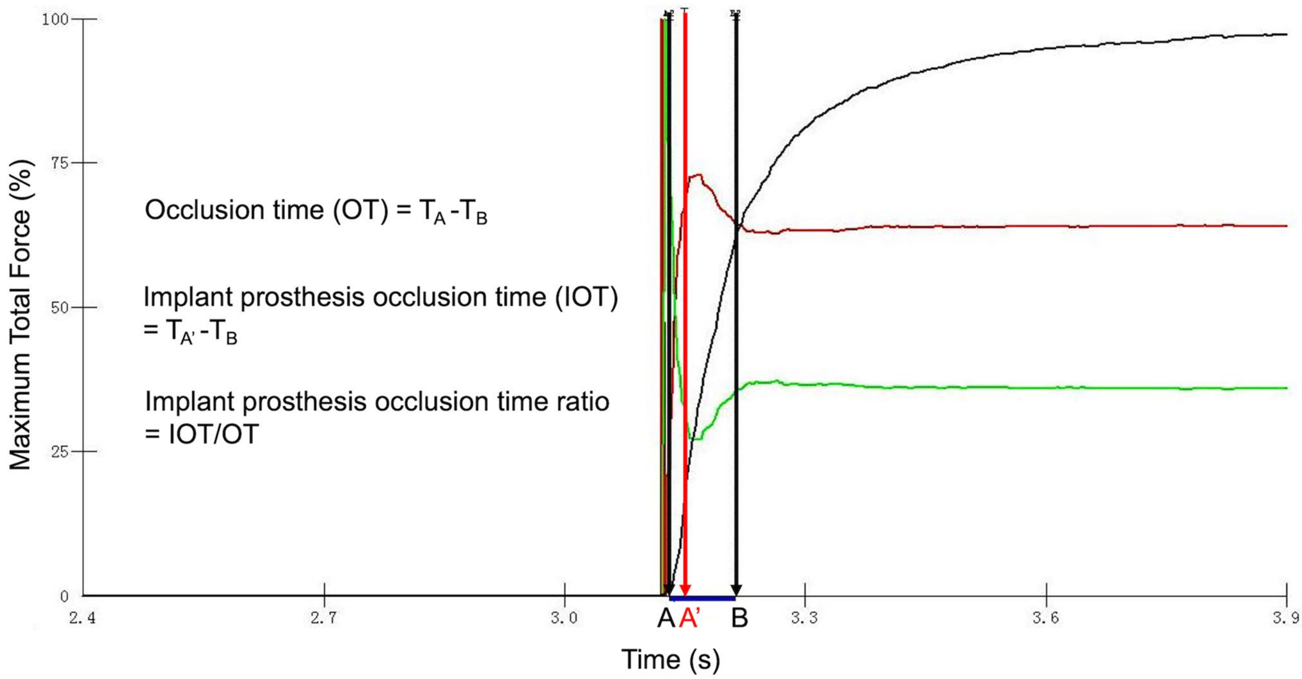

Fig. 2 Graph displaying the arch relative total occlusal force versus time for overall bite process to determine implant occlusion time ratio. The total force is relative. When a scan is taken, the software determines the point at which the highest force was achieved and this is measured to be 100% of the total force. This measurement is then used for the maximum total force line. A line: first occlusal contact of the dentition; T_A: the time of A line; B line: time of maximum intercuspal position determined by the software; T_B: the time of B line; A' line: first occlusal contact of implant-supported single crowns; $T_{A'}$: the time of A' line. The black line maps the relative total occlusal force, the green line maps the left side of the arch, and red line maps the right side of the arch

Considering the time series data of the same implant and patient were not statistically independent, ordinary least square regression analysis was selected to analyze the association between MBL and ROF. If one patient had more than 1 implant-supported single crown included, the observations of the same patient might be related to each other. To make the results more robust, clustered standard errors (CSEs) were used to manipulate the within-patient correlation. The influences of the following parameters were tested as control variables: time after prosthesis delivery, age, gender, smoking habit, implant system, retention method, and superstructure material. Four models of ordinary least square regression analysis with clustering were conducted, including MBL1 and MBL2 with 2 different base type settings respectively. The linear regression models used in the present study were given as follows:

$$MBL1 = \beta_0 + \beta_1 ROF + \beta_2 Age + \beta_3 Gender + \beta_4 Smoking + \beta_5 System + \beta_6 Material + \beta_7 Retention + \beta_8 lnTime + \varepsilon$$

$$MBL2 = \beta_0 + \beta_1 ROF + \beta_2 Age + \beta_3 Gender + \beta_4 Smoking + \beta_5 System + \beta_6 Material + \beta_7 Retention + \beta_8 lnTime + \varepsilon$$

where β is the coefficient and ε is the residual error.

A robust test was conducted where one implant of patients with two implants included was randomly deleted by setting a random number. In the remaining data with one implant per subject, ordinary least square regression analysis was conducted again. Subanalysis of the obtained data stratified for the prosthetic materials was also performed to better report potential differences. Normality and linearity of residuals in the regression model was checked by the Shapiro–Wilk W test and scatter plot. The level of statistical significance was set at two-tailed $P < 0.05$.

Results

Patients and implant-supported prostheses

In total, 33 participants (16 men and 17 women) with 37 posterior implant-supported single crowns were enrolled, including 3 first premolars, 4 second premolars, 5 second

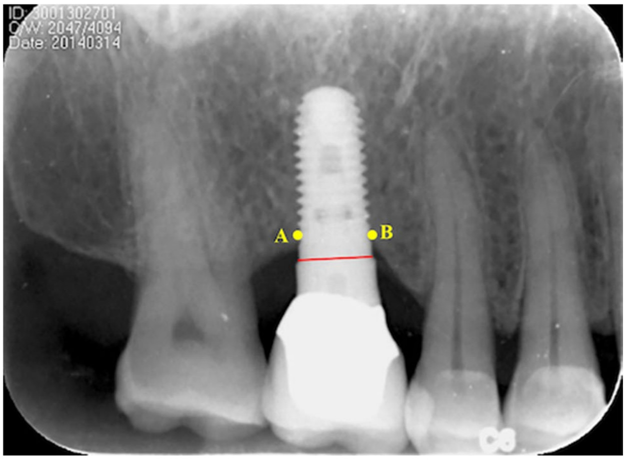

Fig. 3 Standardized radiograph illustrating the mesial and distal bone level measured as the distance from the first bone-to-implant contact (**a**, mesial point; **b**, distal point) to the implant shoulder (red line)

molars, and 25 first molars. The replaced teeth were loss due to caries (81.1%), periodontal disease (16.2%), or congenitally missing (2.7%). The mesial teeth included 4 full crowns and 33 natural teeth, with 3 canines, 4 first premolars, 5 first molars, and 25 second premolars. The systems and types of the implants included Bicon implant (Bicon Dental Implant, Boston, MA, USA), BEGO Semados® S-Line implants (BEGO GmbH & Co. KG, Bremen, Germany), Straumann Standard implants (Institut Straumann AG, Basel, Switzerland), and Osstem GSII implant (Osstem Implant Co., Ltd. Seoul, Korea). The patient demographics, distributions of implant system, retention method, and superstructure material of included prostheses are shown in Table 1.

The ages of the participants ranged from 23.9 to 70 years at the first examination [(42.8 ± 12.9) years]. The follow-up period ranged from 3 to 60 months [(42.4 ± 26.0) months]. During the follow-up period, all participants were free of occlusion-related discomfort. And no implant failure was observed. Six participants (7 implant-supported single crowns) were lost to follow-up or withdrew early because they had either out of touch ($n = 3$), were not compliant ($n = 2$), or had moved from the area ($n = 1$). Seven participants (7 implant-supported single crowns) had crown restorations ($n = 4$), tooth extraction ($n = 2$), or occlusion adjustment ($n = 1$) of natural teeth and stopped participating in follow-up examinations at different time points. Six participants (6 implant-supported single crowns) fractured the veneering material of occlusal surface and dropped out early, yielding a complication rate of 16.2% (6/37). Three implant-supported single crowns were lost because of screw loosening or loss of retention and the participants received new prostheses, yielding a complication rate of 8.1% (3/37). The data of these prostheses prior to the occurrence of dropping out were included. Therefore, 14 implant-supported single crowns underwent occlusal examination at 60 months.

Longitudinal changes in ROFs and IOT:OT

The longitudinal changes in the ROFs of implant-supported single crowns, mesial teeth, and control teeth are shown in Fig. 4, which compared the data of the same patients at two sequential time points as self-control. The ROF of implant-supported single crowns increased significantly ($P = 0.001$) from 2 weeks (7.0 ± 4.2%) to 3 months (9.9 ± 6.8%), whereas those of control natural teeth decreased significantly ($P = 0.02$) from 13.1 ± 6.1 to 11.4 ± 5.5%. ROFs of the implant-supported single crowns continued increasing significantly from 6 to 12 months, 12 to 24 months, and 24 to 36 months ($P < 0.05$). After 36 months, the ROFs of the implant-supported single crowns had no significant increase ($P > 0.05$). The IOT:OT ratio increased significantly between 0.5 and 3 months ($P < 0.001$) and between 3 and 6 months ($P = 0.02$). No significant variation was found after 6 months (Fig. 5).

Table 1 Characteristics of the included patients and implant-supported single crowns

Item	Number	Percentage (%)
Age (years)	42.8 ± 12.9	–
Gender		
Male	16	48
Female	17	52
Smoking habit		
Smoking (< 10/day)	7	21
Non-smoking	26	79
Implant system		
Bicon	18	49
Bego	13	35
Straumann	5	14
Osstem	1	3
Retention method		
Locking taper	16	43
Cement	12	32
Screw	9	24
Superstructure material		
Metal-ceramic	19	51
Metal-resin	16	43
Cast metal	2	5

Comparisons of ROFs between implant-supported single crowns and the control teeth of all the included

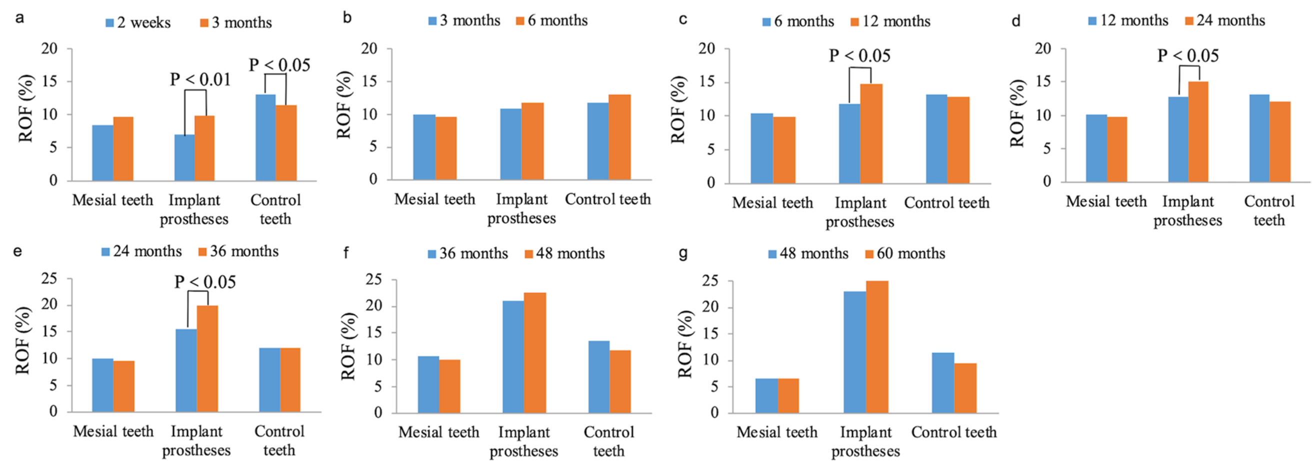

Fig. 4 The longitudinal changes in the relative occlusal forces (ROFs) of implant-supported single crowns, mesial teeth, and control teeth with the data of the same patients at two consecutive time points as self-control. **a** Between 0.5 and 3 months, $n = 30$. **b** Between 3 and 6 months, $n = 18$. **c** Between 6 and 12 months, $n = 20$. **d** Between 12 and 24 months, $n = 19$. **e** Between 24 and 36 months, $n = 19$. **f** Between 36 and 48 months, $n = 18$. **g** Between 48 and 60 months, $n = 14$

Fig. 5 Longitudinal changes in the implant-supported prosthesis occlusion time ratio (IOT:OT ratio)

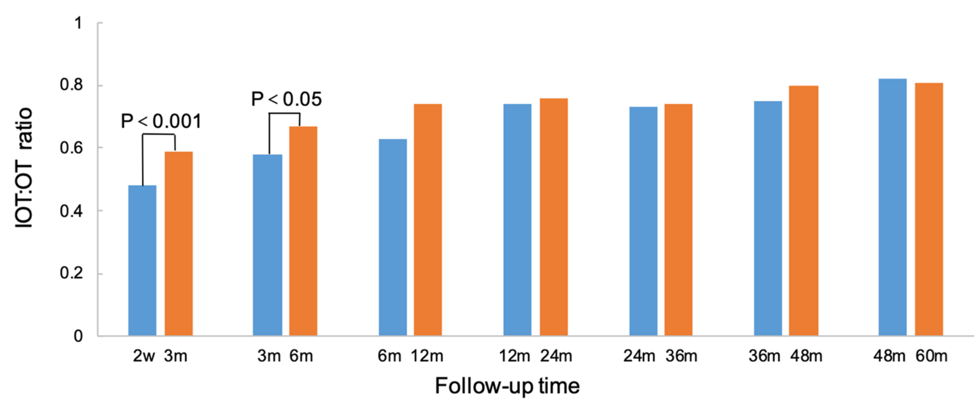

Table 2 Comparisons of relative occlusal force between implant-supported single crowns and control teeth, mean ± SD, or median (lower and upper quartiles)

Time	ROF[a] (%)		P value
	Implant-supported single crowns	Control teeth	
2 weeks ($n = 37$)	7.5 ± 4	13.8 ± 6.0	< 0.001
3 months ($n = 30$)	9.9 ± 6.8	11.4 ± 5.5	0.35
6 months ($n = 27$)	10.6 ± 6.6	12.7 ± 5.8	0.20
12 months ($n = 29$)	13.0 ± 10.6	13.1 ± 7.5	0.97
24 months ($n = 22$)	14.3 ± 11	11.4 ± 6.9	0.35
36 months ($n = 22$)	20.2 ± 14.8	12.6 ± 6.8	0.06
48 months ($n = 18$)	16.7(8.6, 32.4)	9.5(4.9, 18.0)	0.05
60 months ($n = 14$)	23.3 ± 16.8	10.2 ± 5.5	0.02

n number of measurements

[a]Relative occlusal force

data at the same follow-up examination are shown in Table 2. At baseline (2 weeks), the ROFs of the implant-supported single crowns were significantly lower than those of the corresponding control teeth ($P < 0.001$). Then ROFs of the implant-supported single crowns increased and did not differ significantly with those of the control teeth at all the follow-up time points from 3 to 36 months ($P > 0.05$). However, at 48 months and 60 months after restoration, the implant-supported single crowns had significantly higher ROFs than the control teeth ($P < 0.05$).

Considering the sample sizes of 48 and 60 months were below 20, the baseline ROFs of included prostheses were compared with those of excluded prostheses to identify if the sample was representative at 48 and 60 months. And there was no significant difference between the baseline ROFs of included and excluded prostheses at 48 months ($P = 0.28$) and 60 months ($P = 0.81$), indicating that the remaining samples were representative and the results were significant.

Association between marginal bone level and ROF

In the 37 implant-supported single crowns with mean follow-up periods of 42.4 months, 252 sites including the mesial and distal sides of the implants on radiographs were included. MBL was 0.6 ± 0.7 mm ranging from − 1.5 to 2.0 mm. Intraobserver reliability of two measurements of MBL was almost perfect (intraclass correlation coefficient, ICC = 0.98). Considering there were 4 patients that had 2 implant-supported single crowns included in the study, clustering in patient level was used to make our results more robust. Four models of ordinary least square regression analysis with clustering were conducted. The R^2 was 0.67 and 0.68 for regressions of MBL1 and MBL2 respectively. The normality and linearity check showed that the residuals were normally distributed and the assumption of linearity was confirmed. Model specification tests showed that the models were specified correctly and there was no omitted variable. The results of two models including two measurements for MBL with the same base type setting of control variables are shown in Table 3. The robust test randomly selecting one implant per subject showed similar results in terms of the sign and statistical significance of the test variables.

ROF and MBL

In all models of MBL, ROF was significantly related to MBL ($P < 0.05$) with a coefficient of 0.008, which means when the ROF increased by 1%, MBL would increase by 0.008 mm.

Control variables and MBL

The associations between the control variables and MBL can be described as follows:

(1) No adequate statistical evidence could support associations between MBL and patient gender, age, smoking, retention methods, and time after prosthesis delivery at the level of $P < 0.05$.
(2) System_2 (Bego) showed significantly greater MBL than System_1 (Straumann) and System_3 (Bicon) at the level of $P < 0.001$, with no significant difference between System_1 and System_3.
(3) Material_1 (metal-ceramic) had significantly smaller MBL than Material_2 (metal-resin) and Material_3 (cast metal) in all models ($P < 0.05$), with no significant difference between Material_2 and Material_3.
(4) Subanalysis stratified for the materials showed that the association between ROF and MBL is significant only in the stratification of Material_2 (metal-resin), with a coefficient of 0.019 ($P < 0.01$).

Table 3 Results of ordinary least square regression analysis

Two measurements for MBL	MBL1 ($n = 126$)		MBL2 ($n = 126$)	
Parameter	Coefficient	P value	Coefficient	P value
ROF	0.008 [0.002, 0.014]	0.01	0.008 [0.001, 0.015]	0.02
Follow-up time (month)	0.054 [− 0.045, 0.152]	0.28	0.073 [− 0.018, 0.163]	0.11
Age of patient (year)	− 0.001 [− 0.009, 0.011]	0.88	− 0.0001 [− 0.010, 0.010]	0.97
Gender	0.170 [− 0.213, 0.554]	0.37	0.155 [− 0.261, 0.570]	0.45
Smoking	0.214 [− 0.152, 0.579]	0.24	0.226 [− 0.165, 0.616]	0.25
System_2 (Bego)	1.510 [0.864, 2.156]	< 0.001	1.511 [0.840, 2.181]	< 0.001
System_3 (Bicon)	0.187 [− 0.683, 1.056]	0.67	0.178 [− 0.706, 1.062]	0.68
Material_2 (metal-resin)	1.164 [0.601, 1.728]	< 0.001	1.140 [0.563, 1.718]	< 0.001
Material_3 (cast metal)	0.853 [0.221, 1.485]	0.01	0.786 [0.144, 1.428]	0.02
Retention_2 (cement)	0.009 [− 0.455, 0.473]	0.97	0.010 [− 0.487, 0.507]	0.97
Retention_3 (locking taper)	− 0.592 [− 1.640, 0.456]	0.26	− 0.559 [− 1.628, 0.511]	0.30

MBL1 and MBL2 represent two measurements of MBL. The quantities in brackets beside the coefficients are the 95% confidence intervals. System_1 (Straumann) was the base type (benchmark group) of implant system, and its coefficient took the value 0. Similarly, Material_1 (metal-ceramic) was the base type of prosthetic material. And Retention_1 (screw-retain) was the base type of retention method. If the coefficient was negative, MBL of the corresponding variable was lower than that of the base type. Conversely, if the coefficient was positive, MBL of the corresponding variable was higher than that of the base type. And the smaller absolute value of this coefficient, the lower the MBL of corresponding variable

MBL marginal bone level, *ROF* relative occlusal force

Discussion

This clinical study analyzed a 5-year longitudinal variation of occlusion in posterior implant-supported single crowns and its association with MBL. The results of this study support the hypothesis that the ROF of posterior implant-supported single crowns changes with time. But the association between ROF and MBL had limited clinical significance. Both the ROFs and occlusal contact times of implant-supported single crowns increased significantly in the first 3 months. And the ROFs continued increasing significantly from 6- to 36-month follow-up period; after that, the increase slowed down from 36 to 60 months, resulting in a significantly higher ROF of implant-supported single crowns than that of control teeth in 48- and 60-month follow-up.

Although the computerized occlusion analysis system cannot provide the absolute occlusal force, only a percentage of the overall occlusal force, it demonstrates the ability to provide quantifiable force in a time sequence from the initial tooth contact to MIP [17]. T-scan system has been reported to be reliable and valid for measuring the occlusal contact distribution, occlusal contact time, and occlusal contact area, especially in MIP [16, 18, 19]. To improve the validity in measuring relative force, patients who underwent any therapy or condition that may change the occlusal contact distribution of dentition after delivery of the implant-supported single crown were excluded from this study. And all the IOT:OT ratios and ROFs were analyzed as a self-control. Therefore, in the condition of controlling the consistency of investigator and procedure, the reported occlusal changes in this study are clinically relevant.

Continuous eruption of the opposing teeth and the occlusal wear of the remaining natural teeth were considered to play an important role in the increase of ROF and earlier occlusal contact of implant-supported single crowns in this study. The positions of natural teeth in dental arches are constantly changing as a consequence of continued slow tooth eruption and mesial tooth movement of about 0.1 to 0.2 mm annually [20, 21]. Because of the light occlusion after the implant-supported prostheses delivery, the implant-opposing natural dentition may be liable to erupt [11]. Craddock et al. [22] found that 92% of unopposed natural teeth had supra-eruption in excess of 1 mm in 68% of the cases. A clinical study reported that the occlusal wear of natural enamel opposing natural enamel was 17.3 ± 1.88 µm in the premolar region and 35.1 ± 2.6 µm in the molar region after a year of function [23]. Although passive eruption could compensate for the occlusal wear of natural teeth to some extent, there is inconsistency between the rate of wear and continuous eruption, which has significant individual difference [24]. Occlusal wear of the natural teeth may facilitate the change of occlusion, especially before occlusal contacts were established in implant-supported single crowns [25]. Similar occlusal wear would occur in the opposing natural teeth after occlusal contacts were established with implant-supported single crowns. But different wear rate between the prosthetic material and enamel of natural teeth may affect the distribution of occlusion [26].

Another reason for changes in the occlusion of implant-supported prostheses was supposed to be a larger physiologic mobility in natural teeth than implant when subjected to occlusal loading. The mean axial displacement of teeth in the socket are 25–100 µm, whereas the axial motion of osseointegrated implants has been reported approximately 3–5 µm [4]. Thus, implant-supported prostheses were prone to higher occlusal loading and earlier occlusal contact than natural teeth in MIP. On the other sides, tooth loss could significantly affect maximum voluntary bite force and masticatory performance [27]. After prosthetic treatment, both clinical and electromyography examinations showed improvement of masticatory performance and the patients appeared well-adapted to implant-supported prostheses [27]. Therefore, the increase of masticatory muscle force after delivery of implant-supported prostheses may also have a certain effect on the continuing increase of ROF in this study.

The present study has reported the longitudinal changes in ROF and occlusion time of posterior implant-supported single crowns, with the longest follow-up time among all the previous studies concerning the variation of implant-supported prostheses. The increase of ROF indicated that higher percentage of occlusal force was attributed to the implant-supported single crown, which means that the overloading risk could increase. The occlusion of implant-supported single crown should be carefully monitored during follow-up examinations, and occlusal adjustment should be considered when potential overloading occurs, or if premature or interference develops. But does the increasing occlusal force certainly lead to marginal bone loss or even total loss of osseointegration?

Luiz et al. [29] conducted an animal experiment and found that excessive occlusal load applied to implants restored with cantilevers did not cause significant changes in their clinical, radiographic, or histologic outcomes. Another animal experiment [30] concluded that overloading could aggravate the plaque-induced bone loss when peri-implant inflammation was present. Some researchers believed that the magnitude, direction, and period of the forces applying on the bone-implant interface could affect the maintenance of the osseointegration equilibrium and its breakdown [31, 32]. And local and individual factors can influence the stability of the osseointegration; therefore, the biological effect of the occlusal load (functional load or overloading) is highly variable [31, 33].

Importantly, clinical long-term studies focusing on the potential effect of overload on peri-implant bone loss are missing. Specifically, one important clinical scenario which has been always related to potential overload is the use of cantilever extensions. On this topic, several long-term recent studies have found that the presence of a cantilever has no effect on increased risks of implant failure or increased marginal bone loss [34–36]. One of them reported an implant survival rate of 100% with minimal changes in MBL after a mean follow-up of 13.6 years for implant-supported single crowns with cantilever extension in posterior areas [35]. A recent systematic review [37] concluded that the effect of traumatic occlusal forces in peri-implant bone loss was poorly reported and provides little evidence to support a cause-and-effect relationship in humans.

The results of this prospective study could not verify marginal bone loss as a result of excessive occlusal force, neither. The coefficient of ROF means that when the ROF increased by 1%, MBL would increase by only 0.008 mm, which has little clinical significance. Therefore, the statistically significant association between ROF and MBL of implant-supported single crowns in this study has limited clinical significance. Besides, there were other factors which could affect the results to be considered: difference in prosthetic design such as emergence profile and replaced tooth position; the small overall sample size; lack of indexes to evaluate the condition of peri-implant tissues; physiologic change relative to peri-implant bone and tooth position; surgical and prosthetic operation; and patient-related factors such as periodontal health monitoring, oral hygiene, and eating habits [38–40]. The fact that ROF in this study was a percentage of the overall force in MIP, not the absolute value of occlusal force, should also be considered. So far, the impact of increased occlusal loading on implants and whether this could cause marginal bone loss still continue to be a point of controversy.

With the limitations of the sample size and possible bias, implant system and superstructure material of prostheses had significant associations with MBL in this study. Bego implant system showed high risk of marginal bone loss. And noble metal-ceramic superstructure material was low risk. But considering the S-Line implant of Bego system used in this study has a 0.8-mm machined implant shoulder, which was included in the calculation of MBL, the measurement results may be enlarged to an extent. A systematic review demonstrated that there was a statistically significant difference in MBL between three premium implant brands [41]. Implants with platform-switched connection were reported to positively affect bone levels, showing lower peri-implant bone loss [42, 43]. Few studies compared the potential risk of peri-implant bone loss among metal-ceramic, metal-resin, and cast metal implant-supported crowns. Agustin-Panadero et al. [44] evaluated the clinical behavior of implant-supported resin-modified ceramic crowns compared with that of metal-ceramic crowns, and found no significant differences in peri-implant bone loss between the two groups. But implants restored with porcelain fused to base metal alloy were reported to show significantly higher marginal bone loss than those with porcelain fused to noble metal alloy [45]. Resin was found to show up to 20 times higher density of biofilm compared with zirconia and titanium [46]. And greater misfit, which is related to the manufacturing procedures of the prostheses, may increase bacterial accumulation [47]. In the subgingival part of a screw-retained implant-supported crown, surface material, surface roughness, and the nature of inflammatory stimuli might determine the susceptibility to peri-implantitis [48]. All these factors might affect the peri-implant condition to an extent.

The results of this study should be considered within limitations of the sample size and possible bias, including exclusive bias and confounding bias leading to the systematic distortion of the statistic. The rigid exclusion criterion was the main reason for the sample size smaller than 20 at 48- and 60-month follow-up. And the result related to cast metal should be limited because of lack of power due to the small sample size of this stratification. In the future, large sample and long-term studies are still needed to verify the results. Another limitation was that some factors that had been reported to associate with peri-implant bone level were not included in our data, such as degree of plaque accumulation, frequency and content of maintenance care, width of keratinized tissue, soft tissue thickness, and systemic conditions [49, 50]. But the main objective of this study is to explore the occlusal change in posterior implant-supported single crowns and association between the ROF and MBL, rather than exploring the causes of peri-implant bone loss.

Conclusion

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

(1) The initial light occlusion of implant-supported single crown has significant change during 5-year follow-up, which is mainly reflected in the increasing ROF and occlusal contact time.
(2) The association between ROF and MBL of implant-supported single crowns has limited clinical significance.

However, the results should be cautiously interpreted, as they were based on a relatively small sample size.

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Author contribution Q.D. collected and analyzed the data, and draft the article. L.Q. collected the data. Y.T. statistically analyzed the data. L.Z. conceived the ideas and study design, and critically revised and approved the article. Q.X. and Y.Z. revised and approved the article.

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Data availability All data and materials as well as software application or custom code are available from the corresponding author by request.

Declarations

Ethics approval This study was performed in line with the principles of the Declaration of Helsinki. Ethics approval was granted by the Biomedical Institutional Review Board of Peking University School of Stomatology (Oct. 18, 2013/No. PKUSSIRB-201310062). The STROBE statement was used as the guideline for this study.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Competing interests The authors declare no competing interests.

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