Prevalence of proximal contact loss between implant-supported fixed prostheses and adjacent natural teeth and its associated factors: a 7-year prospective study

Objectives: The aim was to analyze the prevalence rate of proximal contact loss (PCL) between implant-fixed prostheses (IFPs) and adjacent teeth and investigate the associated factors.

Material and methods: One hundred fifty participants were recruited for this prospective study from January 2009 to December 2014. Two hundred thirty-four IFPs supported by 384 implants for the posterior region were followed up until June 2016. The contact tightness had been recorded using aluminum strips of different thicknesses with a regular interval after delivery. Proximal contact was considered as lost if the contact tightness was over 50 µm, and statistical analyses were performed to estimate the prevalence rate of PCL and its influential factors.

Results: Among the total 299 proximal contacts of 234 IFPs, 179 were observed as a PCL (59.9%). Bone level and root configuration of the adjacent teeth, the proximal contact position and jaw position of the implant prostheses were statistically significant factors, when analyzed by the cumulative PCL rate using the log-rank test of the Kaplan–Meier method ($P < 0.05$). According to the Cox proportional hazard regression analysis, the proximal contact position, bone level of adjacent teeth and jaw position were revealed to be statistically significant ($P < 0.05$).

Conclusion: PCL should be considered an implant prosthesis complication to which various associated factors could be related. This study revealed that the lower alveolar bone support level of the adjacent teeth, maxillary position of IFPs and mesial site of IFPs were significantly associated with a higher incidence of PCL.

Osseointegrated dental implants have been a routine treatment modality in partial restorative or full-mouth rehabilitation procedures for over 35 years in recent dentistry, and a high success rate of over 95% has been reported. Meanwhile, various post-treatment complications have also been known comprising surgical problems, biological complications, and technical complications including screw loosening, screw fracture, fracture or wear of superstructure material, framework fractures, implant fracture, and loss of the retention of prostheses (Goodacre et al. 2003; Gothenberg et al. 2003). Recently, proximal contact loss (PCL) has been reported as a post-treatment complication (Iemt 2005; Wei et al. 2008; Koori et al. 2010, Wat et al. 2011, Byun et al. 2015; Wong et al. 2015; Ren et al. 2016).

PCL between the implant-supported fixed prostheses (IFPs) and the adjacent teeth indicates a change in the positional relationship between them and can be considered as resulting from the dynamic oral function or the change in other oral structures except teeth and implants, ruling out both pathologic and abnormal influencing factors. Many studies have tried to explain the positional relationship between the implant and surrounding skeletal structure regarding both craniofacial growth and the biofunctional effect.

It has been widely understood that osseointegrated implants maintain their internal relationship under the significant change due to growth and the eruption of adjacent teeth, and they rarely show secondary positional displacement in the sagittal and transverse dimension (Bjork & Skieller 1977; Roberts 1999). However, it was reported that in both young and mature adults, the positional
relationship of implants may be influenced by the growth changes in the jaws and teeth in active growth and in continued and slow growth (Oesterle & Cronin 2000). Slow growth results in adaptive changes in the teeth over time, both vertically and horizontally, which might influence the occlusion and tooth alignment of adjacent natural teeth relative to the single-tooth implant (Odman et al. 1991; Oesterle & Cronin 2000). It was reported that small tooth movements, such as minor erosion of the upper anterior teeth in combination with retroclination, crowding of the upper and lower incisor teeth, and mesial drift of the molars, were observed with significant gender differences through a long-term follow-up after implantation on anterior teeth in a 16-year clinical case report (Jemt 2005, Jemt et al. 2007). Meanwhile, considering the biofunctional aspect, it is generally believed that the position of natural teeth might not be stable in the arch, and the strength of the proximal contact can be significantly influenced by location, tooth type, various head position, chewing, and time of day in complete natural dentitions (Southard et al. 1990; Dorfer et al. 2000; Oh et al. 2004, 2006). In particular, several studies have reported clinical studies relating to PCL between IFPs and teeth and proposed that the rate of PCL at the mesial aspect of the IFPs was significantly higher than that at the distal aspect, attempting to identify any associated factors, the level of prevalence, the pattern, and location. Mesial drifting of adjacent natural teeth was presented as a main cause of PCL at the mesial site of the implant which has no physiologic phenomenon such as mesial migration (Richter 1989). Characteristics such as gender, age increment, vitality of adjacent teeth, the type of opposing dentition, the location of implant prostheses, the strength of occlusal force, and splinting of the adjacent teeth were proposed as potential associated factors to PCL but remained unclear (Wei et al. 2008; Koori et al. 2010; Byun et al. 2015; Wong et al. 2015; Ren et al.2016; Varthis et al. 2016).

The proximal contacts play an important role in the protection of the periodontium against damage caused by food impaction and deflect the food to the buccal or lingual side of the teeth if they are strong enough to resist the separating force without food impaction during chewing. PCL is significantly related to food impaction increasing the periodontal probing depth and inducing progressive bone loss in a tooth with an open proximal contact area (Hancock et al. 1980; Pilcher & Gellin 1998). It could be assumed that PCL between natural teeth and IFPs could have negative effects on the periodontal supporting tissue because peri-implant tissue, of which mucosal sealing can be achieved by only the circular arrangement of periodontal fibers, is more susceptible to damage than that of natural teeth, thus resulting in implant failure (Lindhe et al. 1992, Miyata et al. 2002; Atsuta et al. 2005).

It is thus mandatory to assess the prevalence rate and investigate the associated factors to PCL between the IFPs and adjacent teeth to establish guidelines to prevent PCL for the success of implant prostheses. However, only a few studies have been performed to determine the rate and risk factors of PCL in implant prostheses, and there have been no prospectively designed studies to support the exact event time of PCL using a quantifiable measuring device for proximal contact tightness. The purpose of this study was to investigate the prevalence rate of PCL and identify its potential risk factors in prospective design.

Material and methods

Subjects

One hundred fifty participants who had been treated with implant-supported prostheses between January 2009 and December 2014 and were scheduled for recall examination with immediate, 1-week, 1-, 3-, 6-month, and annual internals until June 2016 in the Department of Advanced General Dentistry, College of dentistry, Yonsei University, Seoul, were involved in this study.

The implant prostheses satisfied the following criteria: [i] The implant prostheses were supported by root form implants; [ii] the natural adjacent teeth or fixed partial denture supported by natural teeth; [iii] the natural teeth or fixed partial denture showed physiologic mobility without any factors related with pathologic movement; and [iv] the implants were placed in the posterior area distal to the canine teeth.

The participants were excluded due to the following: [i] serious systemic disease such as bone metabolic disease; [ii] moderate to advanced periodontitis; [iii] adjacent teeth with malocclusion or secondary occlusal trauma; and [iv] treatment of the adjacent teeth after the delivery of the implant prostheses had been delivered.

In accordance with the selection criteria, 150 patients [male: 67, female: 83] between 21 and 79 years of age participated in this study [mean age, 58.36 years]. The total number of implant prostheses for the study was 234, and the total number of implants was 384. The subject characteristics are presented in Table 1.

The study was performed with the approval of the Institutional Review Board of Yonsei University Dental Hospital, Seoul, Korea (2-2015-0026). Informed consent was obtained from each participant at the time of prosthesis delivery.

Implant placement and prosthetic procedure

All surgical procedures were performed by two dentists [one surgeon or one prosthodontist] according to the manufacturer’s instructions. The implant systems placed in this study were the Implantum [Dentium Co., Seoul, Korea], Branemark System [Nobel Biocare, Zurich, Switzerland], Straumann [Straumann, Basel, Switzerland], and Astra [Dentsply Implants, Mölndal, Sweden]. The implants were the screw type and bone level type. The types of the final prostheses were the cement-retained implant IFPs including the single crown, splinted two- to four-unit FPD supporting two, three, or four implants and were made of all ceramic crowns, gold crowns, and porcelain-fused metal crowns.

The proximal contact surfaces of IFPs of porcelain-fused metal crowns were made of gold to be soldered in case of PCL. The initial proximal contact was controlled under 30 μm with a thin aluminum strip [Dongboo Inc, Inchon, Korea] and checked for dental floss to pass through with high resistance. The definitive occlusion was adjusted with 8-μm shim stock [Union Dental, Seoul, Korea].

Table 1. Characteristics of the subjects

<table>
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<tr>
<td>Female</td>
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<td>40-59</td>
<td>75</td>
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<td>60-</td>
<td>58</td>
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<tr>
<td>Implant number</td>
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<td>Implant-supported fixed prostheses (IFPs)</td>
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<td>Single crown</td>
<td>121</td>
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<tr>
<td>Multiple splinted crown</td>
<td>98</td>
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<tr>
<td>Bridge</td>
<td>15</td>
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<tr>
<td>IFP delivery time (year)</td>
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<td>31</td>
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<td>Bounded</td>
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<td>Free-end</td>
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according to the implant protective occlusion concept (Misch 2005). All IFPs were delivered with Premier Implant Cement (Plymouth Meeting, USA) that was a non-eugenol, temporary resin cement for implant-retained crowns to retrievability of IFPs. The whole prosthetic procedures were performed by one prosthodontist after 3–6 months of healing.

**Clinical measurement**

The proximal contact tightness was evaluated at delivery, at the 1, 3, 6-month follow-up, and then every year thereafter with aluminum strips in addition to taking periapical radiographs for the evaluation of the bone support condition. The thicknesses of the aluminum strip were 5, 10, 20, 25, 30, 40, 50, 60, and 100 μm. Proximal contact was measured from a 5-μm aluminum strip in order by thickness and regarded as “lost” when a strip over 50 μm could be inserted, and the proximal contact tightness was determined as the maximum thickness of the aluminum strip. In cases where the implant prostheses were bounded, both the mesial and distal proximal contacts were recorded; for free-end cases, only mesial proximal contacts were recorded. All measurements were performed by one prosthodontist under the definite protocol of this study.

**Study variables**

Study variables that could affect PCL were grouped as follows:

1) Demographics [age, gender]
2) Adjacent tooth condition [vitality, root configuration, level of bone loss]

The two- or three-unit fixed partial denture (FPD), as well as natural teeth with multi-rooted, was regarded as a multiroot configuration in this study, while the cantilever and prostheses crossing the midline were excluded.

The state of the bone loss level was measured through radiographs. The distance from the cementum–enamel junction (CEJ) of the adjacent teeth to the crestal bone margin [B] was divided by the distance from the CEJ-root apex [A] (Fig. 1).

3) Parafunctional habit: The existence of attrition on posterior teeth was recorded
4) Proximal contact position [mesial or distal] and jaw position [maxilla or mandible] of IFPs
5) Antagonist

The opposing dentition consisted of no opposing dentition, natural teeth, IFPs, removable prostheses, and FPDs.

![Fig. 1. Measurement of the bone support level of adjacent teeth. State of the bone support level of the adjacent teeth = B/A (A: the distance from CEJ to root apex, B: the distance from CEJ to crestal bone margin of adjacent tooth).](image)

**Data management and statistical analysis**

The chronologic changes in the PCL rate were analyzed using the Kaplan–Meier method. The clinical variables were initially analyzed by the log-rank test in univariate analysis, and variables identified to be significant were then submitted to multivariate Cox proportional hazard regression analysis. All statistical analyses were conducted using SPSS version 20 (SPSS Inc, Chicago, IL, USA) (α = 0.05).

**Results**

In accordance with the selection criteria, 150 patients (male: 67, female: 83) were periodically followed up. In total, 299 proximal contacts of 234 IFPs were measured by the same method. Of the 299 proximal contacts, 179 were observed as a contact loss (59.9%). The proximal contact loss rates were analyzed by the Kaplan–Meier method, which indicated continuously increased PCL rates over the 7-year follow-up periods, showing that half of them occurred approximately by 3 years (Fig. 2a). Overall, the cumulative PCL rate was 12.5% at 1 year, 47.6% at 3 years, and 80.8% at 5 years after prosthetic delivery (Fig. 2a). The peak period of PCL incidence appeared at 1.9–2.2 years followed by 3.3–3.6 years, thereafter, the PCL rate decreased (Fig. 2b).

PCL analyses based on the clinical variables were assessed using the Kaplan–Meier method, and significance was identified using the log-rank test (Table 2). Prognostic variables for univariate analyses included gender, age, proximal contact position, antagonist dentition, vitality of the adjacent teeth, attrition, bone level of the adjacent teeth, jaw position, and root configuration of the adjacent teeth. Of the clinical variables evaluated, proximal contact position, bone level of the adjacent teeth, jaw position of implant prostheses, and root configuration of the adjacent teeth were significantly associated with the cumulative PCL rate using the log-rank test (P < 0.05). In particular, the proximal contact position was associated with a significantly higher PCL in 65 bounded IFPs (P = 0.001). Fig. 3 shows the Kaplan–Meier cumulative curves according to [a] age, [b] proximal contact position, [c] vitality of the adjacent teeth, [d] bone level, [e] jaw position, [f] root configuration of the adjacent teeth, and [g] proximal contact position of the bounded IFP cases.

The Cox proportional hazard regression model was constructed by including the significant variables by univariate analysis. The candidate variables were age, proximal contact position, antagonist dentitions, vitality of the adjacent teeth, adjacent bone level, jaw position, and root configuration of the adjacent teeth. Table 3 lists the hazard ratios (HR) and confidence intervals for the selected variables calculated using the Cox proportional hazards model. Consequently, the proximal contact position, bone level of the adjacent teeth, and jaw position were revealed to be significant according to the Cox proportional hazard regression analysis (P < 0.05). In other words, the mesial contact loss rate was almost twice as high as the distal contact (P = 0.011). As the bone support level of the adjacent teeth was decreased, the proximal contact loss was increased steadily (P = 0.002). The bone support level was the strongest association factor among the other variables [bone level 3/8-4/8 HRs = 4.303; P = 0.000]. The maxillary PCL rate was twice as high as that of the mandible (P = 0.001).

**Discussion**

Many researchers have tried to investigate the risk factors of PCL, including craniofacial growth, age, sex, type of opposing dentition, state of teeth restored with implants, vitality of the adjacent teeth, and region of implant prostheses (Jemt 2005; Wei et al. 2008; Koori et al. 2010; Byun et al. 2015; Wong et al. 2015; Ren et al. 2016; Vathis et al. 2016). In the early stage of this study design, mechanical or biofunctional factors could be expected as dominant factors in developing PCL, and IFPs placed in the anterior portion of the arch were excluded in this study because the segmental direction of the occluding force was comparatively more horizontal and different from that of the posterior segment in
dentin. A hypothesis was set that the rate of PCL at the mesial site of IFPs was higher than that of the distal side, and male gender, attrition, younger subject, lower bone support of adjacent teeth, and adjacent teeth with a single root are significantly related to higher risk hazard ratios; additionally, under the removable antagonist prostheses, a low PCL rate would appear.

To control the effect of prosthetic occlusion, all IFPs were fabricated under the one definitive occlusion based on implant protractive occlusion, which means that occlusal contact between the opposing dentition and IFPs was captured with 8-μm shim stock under heavy occlusal loads and was barely detected under light bite force [Misch 2005]. All IFPs were not involved during the mandibular excursive movement.

Dental floss or articulating paper has been conventionally used to evaluate interproximal contacts, but this technique is user dependent and variable. A study suggested that proximal contacts be adjusted enough for 8-μm shim stock to be dragged without tearing [Compagni 1984]. In other studies investigating proximal contact tightness and proximal contact strength of natural dentition [Dorfer et al. 2000; Oh et al. 2004], a strip of 30-μm and a 50-μm metal strip were chosen. For assessment of proximal contact between implant-supported FPD and adjacent natural teeth, two layers of 12-μm shim stock, 38-μm matrix band, and 50-μm metal strip were used to adjust the initial proximal contact [Wei et al. 2008; Koori et al. 2010; Byun et al. 2015; Wong et al. 2015; Ren et al. 2016]. In this study, all proximal contacts between IFPs and natural teeth were adjusted under 30 μm.

In this study, of the 299 proximal contacts, 179 were observed as a contact loss [59.9%] between IFPs and adjacent teeth, which could be considered significant compared with the PCL rates of 52.8% [Varthis et al. 2016], 34% [Byun et al. 2015], 43% [Koori et al. 2010], and 58% [Wei et al. 2008]. This difference in the prevalence rate of PCL could be originated from the different methods of assessing PCL. There is no authentic technique used to identify PCL. The previous studies assessed proximal contact using 50-μm metal strips [Wei et al. 2008; Koori et al. 2010; Ren et al. 2016], 70-μm dental floss [Byun et al. 2015; Varthis et al. 2016], and two layers of 38-μm tofflemire matrix bands [Wong et al. 2015].

In this study, PCL was identified when an aluminum strip over 50 μm could be inserted.

Additionally, the data analyzed by the Kaplan–Meier method demonstrated that the PCL rate was increased continuously over time, showing that half of PCLs occurred approximately by 3 years. A previous study reported the time of half occurrence was 5.5 years [Koori et al. 2010], and another study asserted that 50% of the proximal contacts were lost by approximately 9 years [Byun et al. 2015]. This difference in the half incidence time was postulated to be due to differences in the design of the studies. This study was prospectively designed and could assess the exact time of PCL, but the other studies were crosscut studies in which the exact time data of the PCL of IFPs placed long before the assessment of their studies could not be presented.

The earliest PCL was detected at the 3-month follow-up in this study, which was as early as 3 months post-insertion [Wei et al. 2008]. A recent study investigated consecutive changes in proximal contact tightness [PCT] and concluded that PCT decreased significantly over the 3-month period after IFP delivery, indicating that the deliberate increase in the PCT was not stable and would be diminished because deliberately increasing PCT would act as an orthodontic force to the periodontal tissue around the adjacent teeth [Ren et al. 2016]. Six PCLs occurred within 1 month and were excluded in these data for a more accurate assessment, which could be due to iatrogenic or unseizable factors.

This 7-year prospective study tried to identify the exact time of PCL between IFPs and adjacent teeth. The peak period of PCL incidence appeared at 1.9–2.2 years followed by 3.3–3.6 years, since then, the PCL rate decreased (Fig. 2b). However, this result should be justified whether the early peak period in this study means the real point of high frequency of PCL, as every IFP could be expected to obtain PCL regardless of the treatment time. In other words, the follow-up period in this study varied from 1 to 78 months, and some of the IFPs had been assessed not to have PCL because of the short-term follow-up period; however, in time, they would develop PCL. Therefore, the early stage of frequency presented in Fig. 2b could be changeable in a more long-term study when every IFP has the same follow-up period. However, the result of the late stage could imply that the frequency of PCL

![Fig. 2. (a) Kaplan–Meier survival curve of implant-supported fixed prostheses according to the incidence of PCL. (b) Frequency and onset point of overall PCL.](image-url)
between IFPs and adjacent teeth diminishes after the 1.9- to 3.6-year peak period.

This analysis indicated a higher percentage of PCL at the mesial site of IFPs rather than at the distal site \( P < 0.05 \), agreeing with previous reports \( \text{Wei et al. 2008; Koori et al. 2010; Byun et al. 2015; Wong et al. 2015; Ren et al. 2016; Varthis et al. 2016}. \) However, the study groups were not controlled as bounded cases of IFPs in the previous reports. For a more accurate assessment, in this study, the statistical analysis was performed on the bounded case of IFPs in the maxilla due to the curve of Spee in natural dentition, but PCS remained unchanged in the mandible (Dorfer et al. 2000; Oh et al. 2004, 2006). Chewing activity and higher occlusal force displace natural teeth mesially and cause the proximal contact loss condition. Among the factors investigated, the presence of attrition, state of opposing dentition, bone level of the adjacent teeth, and root configuration of the adjacent teeth could be related to mechanical factors. This seems to be supported by the report that the mesial component of the occluding force results in primarily mesial dislocation of teeth (Southard et al. 1990; Wei et al. 2008).

PCL occurred at a higher rate in single-root adjacent teeth than in multiroot adjacent teeth, a finding that agrees with the results of previous studies (Koori et al. 2010; Byun et al. 2015). In this analysis, the teeth splinted with FPDs were considered a multi-root configuration. These results can be explained by the splinted teeth or multiroot teeth being more resistant to force, a situation that might induce the migration of non-splinted teeth or single-root teeth.

It could be thought that if a force factor can explain the proximal contact loss, the PCL rate might be related to the bone support of adjacent natural teeth; the poorer the bone support of the adjacent teeth is, the higher the PCL rate will be. This study revealed that the bone level of adjacent teeth was significantly related to PCL, indicating that the PCL rate is inversely proportional to the bone support of the adjacent teeth \( P < 0.05; \text{Fig. 3d} \).

Less force would be exerted by an opposing removable partial denture than natural teeth or implants, so the contact loss could increase 0.381 times when the opposing apparatuses are removable partial dentures compared with natural teeth or implants (Koori et al. 2010). By contrast, seven of 10 contacts showed PCL under the removable partial or non-opposing dentition, and no significant relationship appeared to depend on the state of opposing dentition in this study (Table 2). A statistically appropriate distribution of opposing dentition and a large-sized study could provide significant results.

Unlike the hypothesis that the presence of an attrition pattern on the adjacent teeth
Fig. 3. Kaplan–Meier cumulative incidence of PCL according to the (a) patients’ age, (b) proximal contact position, (c) vitality of the adjacent teeth, (d) bone level of the adjacent teeth, (e) jaw position, (f) root configuration of the adjacent teeth, and (g) proximal contact position of the bounded IFPs.
would influence the PCL rate from the point of the biomechanical aspect, there was no significant relationship between the attrition and PCL rate.

Mixed statements were made concerning the influence of the presence of vitality of the adjacent teeth on PCL. A previous study reported that contact loss increased 1.825 times when the adjacent teeth were non-vital with a statistically significant level, and similar results without statistical significance were demonstrated [Koori et al. 2010; Byun et al. 2015]. Similarly, in 57.6% of the vital teeth and 68.3% of the non-vital teeth, proximal contacts were lost without statistical significance (P = 0.099, Table 2), but a tendency that non-vital teeth have a higher PCL rate could be stated.

Contact loss has been demonstrated to also be associated with age and gender. Regarding gender, it had no influence on the PCL rate, which was similar to previous reports [Koori et al. 2010; Byun et al. 2015]. Meanwhile, the PCL rate in this study became higher in the older group (P = 0.10; Fig. 3a), and this result was supported by a study performed by Koori et al., concluding that age affected the loss of PC (P = 0.047).

Proximal contact loss could be a significant devastating factor that induces inflammation around both the implant and tooth; moreover, all proximal contact loss could not be detected without specialized measurement before provoking any periodontal complication, such as food impaction or peri-implantitis. For more prospective success of implant prostheses, the prevalence or associated factors of PCL should be obtained with consent, but the complication of PCL seems to be multifactorial; thus, it is difficult to provide any methods to prevent PCL between the IFPs and adjacent teeth. Regular periodic follow-up for supportive treatment should be practiced, and the gap of the proximal contact should be monitored throughout the follow-up. In practice, the IFPs of the participants who complained about food impaction or had troubles cleaning IFPs due to PCL between IFPs and adjacent teeth were soldered with gold [Degulor®-Lots, Germany] using a laser welding machine (Siro laser tech, Germany) or were added with porcelain after being removed in this study.

In light of the foregoing results, the retrievability of the implant prostheses might be guaranteed in long-term functional and physiological maintenance regardless of the type of IFPs such as cement-retained or screw-retained type. Innovative techniques on the proximal contact surface to regain contact should be revised, as long as they do not impinge the aesthetics, such as Essix retainers [Varthis et al. 2016] or fabricating proximal contact solderable using more durable and adhesive cement for retrievability.

This study has some limitations in the interpretation of research findings due to the method of data collection. Data from all the patients and their implant prostheses, which satisfied inclusion and exclusion criteria in this study, were collected without an a priori sample size calculation. More IFPs were investigated than that of the previous works [Koori et al. 2010; Byun et al. 2015; Wong et al. 2015; Varthis et al. 2016] in which the number of IFPs was within the range of 66–174, and the number of participants was within the range of 45–128. However, to draw definitive conclusions, an a priori sample size/power calculation and the multiplicity of testing and clustering of implants within an individual would be needed.

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Conflict of interest

We have no conflicts of interest.

References


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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. CONSORT 2010 checklist of information to include when reporting a randomised trial.