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Research article

Proximal contact loss between implant prostheses and adjacent natural teeth: A qualitative systematic review of prevalence, influencing factors and implications

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ABSTRACT

Objectives: To evaluate the prevalence of proximal contact loss (PCL) between implant prostheses and natural teeth, and identify the risk factors and implications associated with PCL.

Data/sources: PubMed (MEDLINE), Google Scholar, Cochrane Library Database, Scopus, EMBASE, Open Grey, ScienceDirect, and Web of Science were electronically searched to retrieve clinical studies on PCL around implant prostheses up to September 2021.

Study selection: A total of 19 studies were eligible. The short-term studies (less than 2 years) revealed a PCL prevalence of 11–30%, the medium-term studies (2–5 years) indicated a PCL prevalence of 13–65%, and the long-term studies (more than 5 years) showed a PCL prevalence of 29–83.3%. The likely influencing factors were the duration of service and the mesial location of proximal contacts. Other factors, such as occlusion, vitality of adjacent teeth, implant location, patient age and splinting had a less obvious relation to PCL. The reported implications of PCL were food impaction and patient dissatisfaction. Bone loss, peri-implant inflammation, bleeding on probing and pocket depth had a less clear association with PCL.

Conclusions: PCL development between implant prostheses and natural teeth is frequent, inevitable and progressive. While the review identified several influencing factors and implications of PCL, future research is needed to outline the influence of prosthesis design on PCL and food impaction.

Clinical significance: Patients with implant prostheses should be informed about PCL likelihood and the risk of food impaction around implant prostheses. The proximal contact quality and its implications should be monitored during the review visits.

1. Introduction

The replacement of missing teeth with dental implants is a popular treatment that has been proven to be successful clinically. Despite the impressive outcome of implant dentistry, biological and mechanical complications are still inevitable and frequently observed [1, 2]. This involves peri-implant bone loss, soft tissue inflammation, ceramic veneer chipping, screw complications and failure of components. In addition, as implant prostheses are expected to serve over a long duration through the patient lifespan, it is critical to observe the aging-related changes of implant prostheses [3, 4, 5, 6, 7, 8]. A less frequently discussed complication is the alteration of the relationship between the implant prostheses and natural teeth, leading to proximal contact loss (PCL) between implant prostheses and adjacent natural teeth [1, 9, 10, 11, 12].

PCL between implant prostheses and natural teeth can have significant implications such as food impaction, pain, patient discomfort and dissatisfaction [13, 14, 15, 16, 17, 18]. Potentially, soft tissue inflammation, and loss of soft tissue and bone may develop [19, 20, 21, 22]. A progressive increase of PCL may eventually mandate interventions such as restoration of adjacent teeth, repairing the prosthesis or even replacement of the implant prosthesis. This can lead to major financial implications and inconvenience for the patients and the clinicians. Several studies have attempted to evaluate the prevalence of PCL between implant prostheses and natural teeth, and have confirmed that the PCL rate of implant prostheses is greater than the PCL rate between natural teeth [2, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 23, 24, 25]. However, the paucity of the available studies and the lack of uniformity among them may prevent a consistent conclusion and identification of

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the risk factors. Specifically, there is a lack of information on what is an acceptable level of proximal contact tightness between implant prostheses and natural teeth, and there are no guidelines on when to intervene. Thus, it is important to critically and qualitatively evaluate the rate of PCL, contributing factors to PCL, and implications of PCL for the purpose of establishing some clinically relevant guidelines to manage PCL. Therefore, the aim of this qualitative systematic review was to evaluate the prevalence of PCL, identify the risk factors that can influence the prevalence of PCL, and identify the implications of PCL.

2. Methods

The methodology of this systematic review followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (http://www.prismastatement.org). The review was registered at the International prospective register of systematic reviews (PROSPERO) (registration number: CRD42021237518). The search question was defined according to the population, intervention, comparisons and outcomes (PICO) format. The PICO details were: population = patients with single implant or multiple implant prostheses; intervention = proximal contact loss; comparison = intact proximal contact; outcome = prevalence and implications of PCL.

2.1. Search strategy

The literature search was conducted electronically through PubMed (MEDLINE) and Google Scholar. The PubMed search involved a combination of the following terms ('implant') AND ('proximal' OR 'interproximal' OR 'embrasure' OR 'contact') AND ('loss' OR 'looseness' OR 'open' OR 'tightness') AND ('oral' OR 'dental'). The retrieved articles were saved in a reference management software (EndNote, version X9, Thomson Reuters). Additional articles were searched via the Google Scholar search engine by combining the following key words: 'implant', 'proximal', 'embrasure', 'contact', 'loss', 'looseness', and 'open'. Additional databases (Cochrane Library Database, Scopus, EMBASE, Open Grey, ScienceDirect, and Web of Science) were used to search for possible articles using similar key words. The duplicate articles from the different searches were eliminated. Articles published from year 2000 were considered and the search was completed in September 2021.

2.2. Inclusion and exclusion criteria

The studies were considered for inclusion if they were clinical studies published in peer-reviewed journals, evaluating the prevalence or implications of PCL between implant prostheses and adjacent natural teeth, implementing specific methods of evaluating PCL, formally evaluating proximal contact quality of all of their patients, and published in the English language. Studies with a follow-up duration of less than 1 year, and studies including less than 10 patients were excluded.

2.3. Study selection

From the collected literature, the selection of the studies was finalized according to the following stages: evaluation of the title's relevance, evaluation of the abstract's relevance, and full-text analysis and matching against the inclusion criteria. The literature search was supplemented by manual searching of the list of references of the included studies.

2.4. Quality assessment

The Quality Assessment of Diagnostic Accuracy Studies (QUADAS) tool [26] was applied to evaluate the risk of bias of the studies. Fourteen questions (Table 1) were applied for every study. Based on the available information, a score of 1 was given if the answer was "yes". If the answer was "no" or "unclear", a score of 0 was given. Therefore, the highest possible score is 14, and a high score is indicative of a lower risk of bias.

Table 1. Quality Assessment of Diagnostic Accuracy Studies (QUADAS) guidelines and scoring system.

QUADAS questions	Score	
	Yes (1)	No/Unclear (0)
Was the spectrum of patients/implant prostheses representative of what will be diagnosed in practice?	( )	( )
Were the selection criteria clearly described?	( )	( )
Is the reference method likely to correctly classify the target condition?	( )	( )
Is the time period between reference method and test method short enough to be reasonably sure that the target condition did not change between the 2 tests?	( )	( )
Did the whole sample, or a random selection of the sample, receive verification using a reference standard of diagnosis?	( )	( )
Did the patients/implant prostheses receive the same reference method regardless of the test method results?	( )	( )
Was the reference method independent of the test method (i.e. the test method did not form part of the reference standard)?	( )	( )
Was the execution of the test method described in sufficient detail to permit replication of the test?	( )	( )
Was the execution of the reference method described in sufficient detail to permit its replication?	( )	( )
Were the test method results interpreted without knowledge of the result of the reference method?	( )	( )
Were the reference method results interpreted without knowledge of the results of the test method?	( )	( )
Were the same clinical data available when test results were interpreted as would be available when the test is used in practice?	( )	( )
Were the uninterpretable/intermediate test results reported?	( )	( )
Were withdrawals from the study explained?	( )	( )

2.5. Outcome variables

From every included article, the following information was obtained: study design, setting, duration, patient number and age, implant restoration number, prosthesis type, restoration design and implant type. In addition, as some studies differentiated between mesial and distal surfaces of the prosthesis, the proximal surface number was extracted from the studies. The following outcome variables were extracted from the studies: percentage of PCL and the annual rate of PCL. If the percentage of PCL was not clearly stated by the study, it was calculated by relating the total number of prostheses and/or surfaces with PCL against the total number of prostheses and/or surfaces included in the study. The annual rate of PCL was measured by dividing the percentage of PCL on the duration of the study. In addition, whenever available, information on the contributing factors to PCL, and the implications of PCL were collected. Due to the heterogeneity of the data, including variations in the studies' designs and durations, and variations in PCL evaluation methods, conducting a meta-analysis was not feasible.

3. Results

3.1. Search results

The initial electronic search retrieved a total of 2423 studies (Figure 1). After screening the titles and abstracts, 29 studies were eligible for full-text analysis. After matching the remaining studies against the inclusion criteria, 17 studies were found to be suitable for inclusion. Searching the references of the literature identified an additional 2 relevant studies. Therefore, the total number of included studies in this review was 19 studies (Table 2) [2, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 23, 24, 25, 27, 28, 29]. The included studies evaluated the proximal contact quality via dental floss, metal strip, metal strip attached to force gauge, and radiograph.

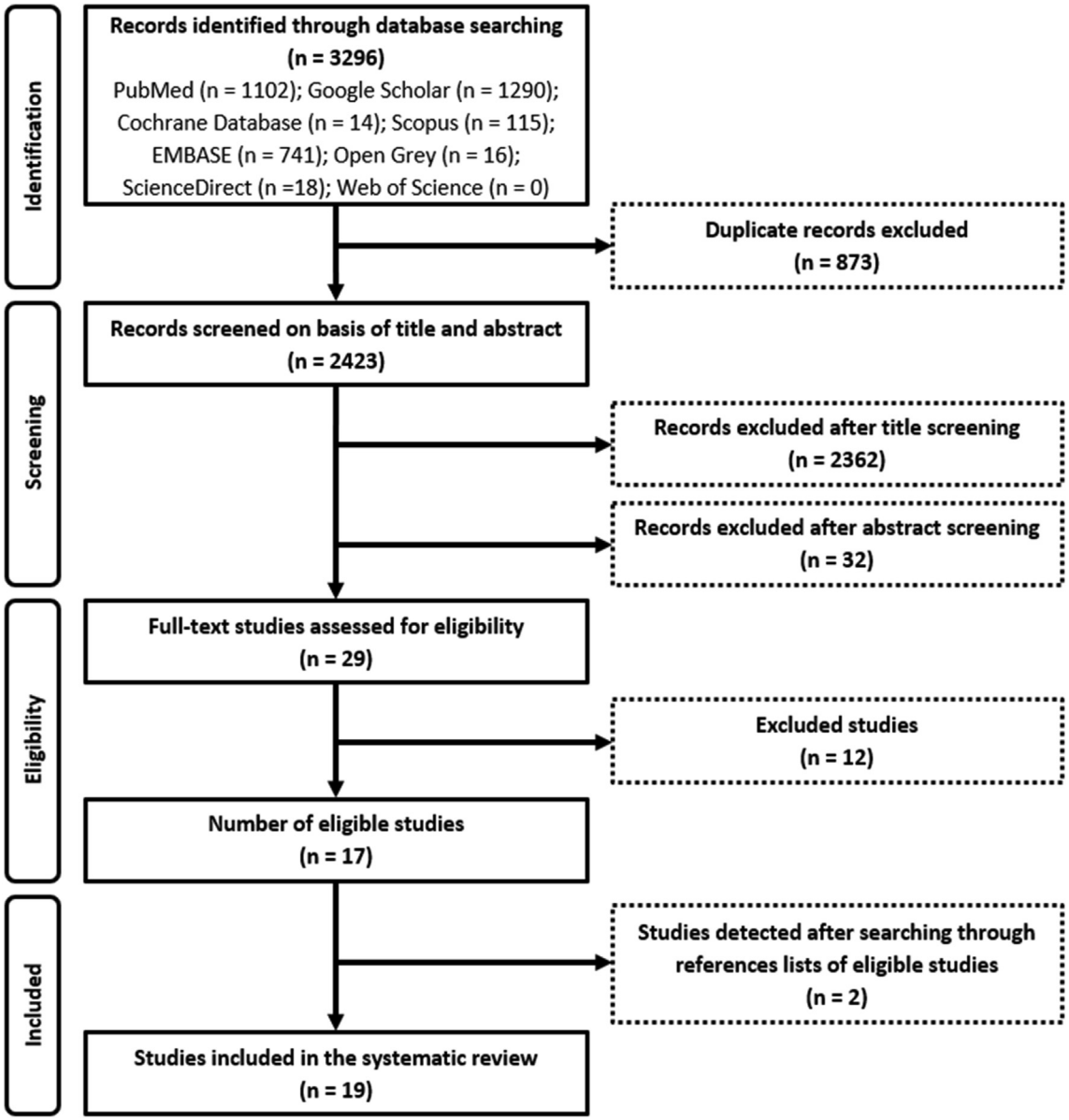

Figure 1. Flowchart of the literature search according to PRISMA guidelines.

3.2. PCL prevalence

A total of 18 studies measured the prevalence of PCL at the prosthesis or surface level [2, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 23, 24, 25, 27, 29]. A consistent observation across the included studies was that the longer the duration of service, the greater the prevalence of PCL [10, 12, 13, 14, 15, 16, 17, 18, 19, 27, 28, 29]. Some studies indicated that the first PCL can occur within a few months of service, specifically after 3 months [12, 28], 4 months [14], and 6 months [17]. The approximate prevalence rate of PCL ranged from 3% to 33.5% per year, with a general tendency for the rate to be close to 10% per year. The considerable disparity in the reporting of PCL rates can be attributed to variations in the methods of evaluation, subjective operators' evaluation, duration of the study, and study design. The studies can be classified according to their duration into 3 categories: short-term (less than 2 years), medium-term (2–5 years) and long-term (more than 5 years) studies.

The short-term studies revealed a noticeable prevalence of early PCL. After evaluating proximal contact tightness for 18 participants, Ren et al noticed reduction in tightness after 3 months of service [28]. Kandathilparambil et al reported a reduction in proximal contact tightness in 25.3%–57.9% of the evaluated proximal surfaces [25]. Within 1 year of service, the prevalence of PCL was found to be 11% [19], 12.5% [13] and 24.3% [23]. A prospective study found a 16.5% incidence of PCL after 1 year, with an increase to 25.7% after 2 years [27]. A similar prospective study reported a 3.3% incidence of PCL after 1 year and 21.3% after 2 years [29]. Another study showed 30% incidence of PCL in 1 year, with PCL incidence reduced to 15% if the patients were wearing a retainer [25].

The studies that reported the medium-term outcomes confirmed the progressive increase in PCL prevalence. Wong et al observed that 65% of prostheses showed PCL within 3.9 years of service [17]. Pang et al reported a cumulative PCL rate of 47.6% after an average period of 3 years of delivery, with peak period of loss at 2 years and 3.5 years [13]. French et al reported that 17% of implants suffered from PCL after 4.5 years of service [19]. Similarly, after 2 years, Chanthasan et al found a 19.2% prevalence of PCL [24]. In a 3–5 years study, Saber et al found 32.8% of the prostheses had PCL [20]. Likewise, in 2–5 years of service, Liang et al reported 26.2% of PCL at the mesial surface [14]. A radiographic study found 13.3% of the prostheses had PCL after an average service duration of 3.1 years [18]. Therefore, the medium-term studies indicated a consistent increase of PCL, with a prevalence of 13%–65%.

Table 2. Summary of the included studies.

Study (year)	Study quality score (0–14)	Study details			Restoration details						Method(s) of evaluation	Outcome	
		Design	Setting	Patient number (age average or range)	Implant restoration number (proximal contact number)	Study duration	Prosthesis type	Location	Retention mechanism	Implant type (connection)		Percentage of proximal contact loss	Approximate rate per year
Wei et al (2008) [12]	8	R	University	28 patients (57.8 years)	55 restorations	1.3–2.2 years	NA	Posterior	NA	NA	50 μm metal strip Occlusal analysis by dental prescale system	58.2% of prostheses	33.5% per year
Koori et al (2010) [16]	9	R	University	105 patients (20–78 years)	146 restorations 186 proximal contacts (141 mesial contacts; 45 distal contacts)	Up to 10.3 years Average of 5.5 years	Single and multiunit	Anterior and posterior	NA	Nobel Biocare (Branemark) Nobel Biocare (Replace) Steri-Oss Straumann Calcitek (integral) IMZ	50 μm thick gauge	43.0% of proximal contacts 51.8% of mesial contacts 15.6% of distal contacts	9.6% per year
Byun et al (2015) [15]	9	R	Hospital	94 patients (56 years)	135 restorations 191 proximal contacts (134 mesial contacts; 57 distal contacts)	Up to 13 years Average of 4.8 years	Single and multiunit	Anterior and posterior	NA	NA	Dental floss Evaluated food impaction, periodontal/peri-implant tissue conditions and oral hygiene Radiographic assessment Evaluated potential influencing factors	34.0% of proximal contacts 38.1% of mesial contacts 24.6% of distal contacts	7.2% per year
Jeong and Chang (2015) [21]	10	R	University hospital	100 patients (56 years)	150 restorations 215 proximal contacts	Up to 13 years Average of 4.6 years	Single and multiunit	Mostly posterior	NA	NA	Dental floss Evaluated impact of proximal contact loss and embrasure dimensions on food impaction and biological variables (periodontal/peri-implant tissue conditions and bone level)	34.0% of proximal contacts	NA
Wong et al (2015) [17]	9	R	Hospital	45 patients (45 years)	66 restorations	3.9 years	Single and multiunit	Posterior	Screw and cement	Nobel Biocare	Measured proximal contact quality by insertion of 38 μm matrix bands Adjacent teeth mobility evaluation with periotest Self-reported questionnaire	65.0% of prostheses	16.0%
Ren et al (2016) [28]	10	P	Hospital	18 patients (40 years)	18 restorations 36 proximal contacts (18 mesial contacts; 18 distal contacts)	1 year	Single	Posterior	Screw and cement	Nobel Biocare (Replace) Ankylos	Custom made contact pressure system based on 50 μm thick metal strip Measured proximal contact tightness over 3 durations (insertion, 3 months review, and 1 year review)	After 3 months: 73.3% reduction of mesial contact tightness 64.8% reduction for distal contact tightness	NA

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Table 2 (*continued*)

Study (year)	Study quality score (0–14)	Study details			Restoration details						Method(s) of evaluation	Outcome	
		Design	Setting	Patient number (age average or range)	Implant restoration number (proximal contact number)	Study duration	Prosthesis type	Location	Retention mechanism	Implant type (connection)		Percentage of proximal contact loss	Approximate rate per year
												After 1 year: 83.0% reduction of mesial contact tightness 48.5% reduction of distal contact tightness	
Varthis et al (2016) [11]	9	R	University hospital	128 patients (19–91 years)	174 restorations	Up to 11 years	Single	Anterior and posterior	Screw and cement	Nobel Biocare Straumann, Astra Biomet 3i Neoss	70 μm thick dental floss	52.8% of proximal contacts 78.2% of mesial contacts 21.8% of distal contacts	9.4%
Pang et al (2017) [13]	10	P	University	150 patients (58.4 years)	234 restorations 299 proximal contacts (234 mesial contacts; 65 distal contacts)	7 years	Single and multiunit	Posterior	Screw and cement	Nobel Biocare (Branemark) Straumann (bone level) Astra Implantium	50 μm aluminum strips	59.9% of proximal contacts 66.2% of mesial contacts 36.9% of distal contacts	8.6%
French et al (2019) [19]	9	R	Private practice	NA	4325 implants	Up to 21 years Average of 4.5 years	Single and multiunit	Anterior and posterior	NA	Nobel Biocare (Replace) Straumann (tissue level)	Dental floss Radiographic assessment Evaluation of peri-implant tissue condition and implant mucosal index	16.9% of prostheses 85.4% of prostheses had mesial open contact 11.6% of prostheses had distal open contact 3.9% of prostheses had mesial and distal open contacts	3.8%
Shi et al (2019) [23]	10	P	Hospital	74 patients (43.6 years)	144 proximal contacts (74 mesial contacts; 70 distal contacts)	1 year	Single and multiunit	Posterior	Screw and cement	NA	Dental floss	24.3% of proximal contacts 23.0% of mesial contacts 25.7% of distal contacts	24.3%

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Table 2 (*continued*)

Study (year)	Study quality score (0–14)	Study details			Restoration details						Method(s) of evaluation	Outcome	
		Design	Setting	Patient number (age average or range)	Implant restoration number (proximal contact number)	Study duration	Prosthesis type	Location	Retention mechanism	Implant type (connection)		Percentage of proximal contact loss	Approximate rate per year
Chanthasan et al (2020) [24]	9	R	University	132 patients (55.6 years)	215 restorations 302 proximal contacts (174 mesial contacts; 128 distal contacts)	Up to 14 years Average of 2.2 years	Single	Posterior	NA	NA	Dental floss Clinical examination of papilla appearance, food impaction in the proximal area and plaque presence Evaluated the association between food impaction and the presence of BoP	19.2% of proximal contacts	8.7%
Kandathilparambil et al (2020) [25]	11	P	Hospital	40 patients (18–50 years)	40 restorations	1 year	Single	Posterior	Screw and cement	Touareg Adin	Digital force gauge with 50 μm thick metal strip	22.5% of proximal contacts With retainer: 15.0% opening of the mesial contact 25.3% reduction of mesial contact tightness 33.7% reduction of distal contact tightness Without retainer: 30% opening of the mesial contact 57.9% reduction of mesial contact tightness 38.9% reduction of distal contact tightness	22.5%
Liang et al (2020) [14]	10	R	Hospital	317 patients (54 years)	549 restorations 850 proximal contacts (549 mesial contacts; 301 distal contacts)	Up to 18 years	Single and multiunit	Posterior	Screw and cement	Straumann Biomet 3i Xive	Dental floss	19.1% of proximal contacts 27.0% of mesial contacts 5.0% of distal contacts	3.0%
Muhlemann et al (2020) [2]	11	P	University	76 patients (57.7 years)	76 restorations 120 proximal contact (74 mesial contacts;	1 year	Single	Posterior	Screw	Straumann (bone level)	Dental floss	3.3% of proximal contacts 4.1% of mesial contacts	3.3%

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Table 2 (*continued*)

Study (year)	Study quality score (0–14)	Study details			Restoration details						Method(s) of evaluation	Outcome	
		Design	Setting	Patient number (age average or range)	Implant restoration number (proximal contact number)	Study duration	Prosthesis type	Location	Retention mechanism	Implant type (connection)		Percentage of proximal contact loss	Approximate rate per year
					46 distal contacts)							2.2% of distal contacts	
Saber et al (2020) [20]	9	R	University	83 patients (57 years)	183 restorations 183 proximal contacts (121 mesial contacts; 62 distal contact)	Up to 5 years	Single	Anterior and posterior	Screw and cement	Nobel Biocare Straumann Astra Biomet 3i Dio	70 μm dental floss Radiographic evaluation	32.8% of proximal contacts 42.1% of mesial contacts 14.5% of distal contacts	12.5%
Yen et al (2020) [18]	9	R	Hospital	147 patients	180 restorations 296 proximal contacts (168 mesial contacts; 128 distal contacts)	Average of 3.1 years	Single and multiunit	Anterior and posterior	Screw and cement	NA	Radiographic evaluation Evaluation of the possible risk factors (age, sex, diabetes, smoking, and bruxism) and prosthesis-related factors (follow-up period, arch location, splinting, prosthesis materials, retention mechanism, implant connection, adjacent teeth condition)	13.3% of implants 8.8% of proximal contacts 13.7% of mesial contacts 2.3% of distal contacts	4.3% at implant level 2.8% at surface level
Abduo et al (2021) [27]	10	P	University hospital	35 patients	37 restorations 71 proximal contacts (37 mesial contacts; 34 distal contacts)	2 years	Single	Anterior and posterior	Screw	Biomet 3i	Dental floss	25.7% of proximal contacts 32.4% of mesial contacts 20.0% of distal contacts	12.8%
Bompolaki et al (2020) [10]	9	R	University	83 patients (63.5 years)	118 restorations	Up to 10 years Average of 4 years	Single	Posterior	Screw	NA	Dental floss Measured the size of the contact by insertion of shimstock Evaluated peri-implant probing depth and presence of BoP Evaluated patient perception about food impaction	48.8% of mesial contacts 26.7% of distal contacts	9.4%
Wolfart et al (2021) [29]	10	P	University	41 patients (47 years)	56 restorations 100 proximal contacts (56 mesial contacts; 46 distal contacts)	2 years	Single	Posterior	Screw and cement	Camlog	50 μm metal strip	21.3% of proximal contacts 26.4% of mesial contacts 14.6% of distal contacts	10.6%

The long-term studies of more than 5 years found the prevalence of PCL to range from 29% to 83.3%. In a 5.5 year study, Koori et al found PCL to occur in 43% of surfaces [16]. Byun et al found a prevalence of 34% of PCL after 5 years, and the rate consistently increased over the duration of the study (13 years). Specifically, 50% of proximal contacts were lost in 9 years [15]. Another study found the prevalence of PCL to be 34% in up to 13 years of service [21]. Wong et al observed that 83.3% of prostheses had PCL after a service duration of 5–12 years. In a study of up to 11 years duration, 52.8% of prostheses showed PCL [11]. Pang et al found 59.9% of proximal contacts were lost in 7 years [13]. French et al reported that 29% of the implants had PCL at 8 years [19]. Liang et al reported that PCL occurred in 27% of mesial surfaces and 5% of distal surfaces after 5 years [14]. On average, 50% of mesial proximal contacts were open by 9 years, and 20% of distal proximal contacts were open by 12 years. Similarly, Bompolaki et al found 48.8% of mesial proximal contacts and 26.7% of distal proximal contacts were open within 10 years [10]. In addition to the prevalence of PCL, Wong et al observed that the magnitude of interproximal space between the implant prostheses and adjacent teeth to be greater for prostheses with more than 5 years of service than those with less than 5 years of service [17].

3.3. Influencing factors

The included studies evaluated several possible contributing factors that may influence the prevalence of open proximal contacts. This involved proximal contact location, implant location, occlusion, patient age, gender, vitality of adjacent teeth, splinting, restoration design, bone level and implant maintenance.

3.3.1. Proximal contact location

Consistently, the mesial surfaces tended to suffer from more PCL and at an earlier duration than the distal surfaces [10, 11, 13, 14, 15, 16, 18, 19, 20, 21, 25, 27, 28, 29]. The majority of the studies reported a significant difference between the prevalence of mesial and distal PCL [10, 11, 13, 14, 15, 16, 18, 19, 20, 21, 25, 28]. Specifically, mesial PCL was found to be more prevalent than distal PCL by a factor of 2 [10,13,15], 3 [11,16,20], 5 [14], or 7 [19]. On the other hand, some studies did not find a significant difference in the prevalence of mesial and distal PCL [23, 27]. Therefore, as a whole, the mesial surfaces are more likely to suffer from PCL and the distal surfaces are still susceptible to PCL.

3.3.2. Implant location

There is no clear pattern on the effect of inter-arch or intra-arch implant locations on PCL. Several studies found that implant sites at the posterior segment (premolars vs molars) had a minimal influence on the PCL prevalence [12, 17, 23]. Pang et al reported that single-rooted adjacent natural teeth tended to be associated with more PCL than multi-rooted adjacent natural teeth (71.1% vs 48.3%) [13]. On the other hand, Bompolaki et al found that the implants in premolar sites had tighter mesial proximal contacts than implants in molar sites [10]. Koori et al observed a similar PCL rate for anterior and posterior implants [16], while French et al reported greater PCL prevalence for posterior implants than anterior implants [19].

Three studies found more PCL in the mandible than in the maxilla [16, 19, 23], however, only 2 of them found the effect of location to be significant [19, 23]. Another study reported a significantly greater prevalence of PCL in the maxilla than in the mandible [13]. Three studies confirmed the lack of association between the arch and PCL prevalence [10, 18, 20].

3.3.3. Occlusion

Two of the included studies found an effect of the opposing occlusion [16, 19], while 2 studies did not [13, 17]. Koori et al found significantly less prevalence of PCL if the occluding dentitions were removable prostheses instead of natural teeth (38% less likely to develop PCL) [16]. Similarly, French et al reported that 18.9% of implant prostheses in occlusion had PCL, while 15.4% of implant prostheses out of occlusion had PCL [19]. On the contrary, three studies reported no association between the opposing dentition (natural dentition, fixed prostheses, removable prostheses, implant prostheses or missing teeth) and the prevalence of PCL [10, 13, 17]. After evaluation of the implications of parafunctional activities on PCL prevalence, 3 studies did not observe an association [13, 17, 23]. By investigating the effect of dynamic occlusion (canine guidance vs group function), 1 study did not notice any implication on PCL [14]. The daily use of an occlusal splint in either arch was not found to reduce the prevalence of PCL [10]. By measuring the magnitude and direction of occlusal forces, Wei et al found a tendency for a high proportion of lingual and anterior forces and high occlusal force distribution in the intercanine region in patients with PCL [12]. Overall, while occlusion may have an effect on PCL, the complexity of occlusal variables and the ongoing changes in occlusion and the masticatory system may make it difficult to delineate a clear relation with PCL.

3.3.4. Patient age and gender

A total of 9 studies evaluated the effect of patient age on the prevalence of PCL [10, 12, 13, 14, 15, 16, 17, 18, 20]. Three studies found that age was positively correlated to PCL [14, 16, 17]. Specifically, the older the patient, the greater the prevalence of mesial PCL, and patients older than 50 years had a greater risk of PCL than patients younger than 50 years [14]. On the other hand, 6 studies found a minimal effect of patient age [10, 12, 13, 15, 18, 20]. Therefore, in general, the effect of patient age seems minimal, and was found to be insignificant by the majority of the studies. The observed differences can be due to the older patients having more dental related complications, restorative treatment or periodontal involvements. The patient's gender was evaluated by 8 studies, and was found by 7 of them to have a minimal effect on PCL [13, 16, 17, 18, 19, 20, 23]. One study observed that females had tighter mesial and distal contacts than males, with a significant difference at the distal aspect [10].

3.3.5. Vitality of adjacent teeth

Five studies evaluated the vitality of adjacent teeth [10, 13, 14, 16, 18]. Three of them found no relation between vitality and PCL prevalence [10, 13, 18]. Koori et al observed that the lack of vitality of adjacent teeth had significantly increased the prevalence of the mesial PCL, but not the distal PCL [16]. On the other hand, Liang et al reported that the nonvital adjacent teeth were associated with more distal PCL [14].

3.3.6. Splinting

Two studies evaluated the effect of splinting of adjacent teeth on PCL. One of them found splinting was associated with less PCL at the mesial surface [16]. The other study reported a 2.5 times higher chance of PCL when the adjacent teeth to the implants were splinted with fixed dental prostheses [15].

Six studies compared single implant prostheses against splinted implant prostheses in relation to PCL [14, 15, 16, 17, 18, 23]. Four studies found splinted implant prostheses tended to be associated with more PCL than single implant prostheses [14, 15, 16, 17]. One of them found the difference to be significant only for the mesial PCL [14]. The remaining 2 studies did not reveal a difference between single and splinted implant prostheses [18, 23].

3.3.7. Restoration design

In relation to the dimension of the proximal embrasure region, Buyn et al reported a minimal impact of the contact point vertical level and horizontal implant-tooth distance on the rate of PCL [15]. Jeong and Chang conducted a more detailed analysis of the proximal embrasure region and included embrasure surface area, horizontal implant-tooth distance and contact point level [21]. The only variable that influenced the food impaction was the embrasure surface area (the triangle formed between the proximal surfaces of the implant crown and adjacent natural tooth with the crest of the bone), where an enlarged area was associated

with increased food impaction [21]. Liang et al observed significantly greater mesial PCL with the presence of the plunger cusp in the opposing jaw [14].

According to 3 studies, there was no effect of the retention mechanism (screw vs cement) on PCL [17, 18, 23]. Two studies found cement-retained restorations to be associated with less PCL incidence than screw-retained restorations. However, 1 of them reported this tendency on the distal PC [14], while the other study reported the tendency on the mesial PC [29].

3.3.8. Bone level

Two studies found that the bone level around the implant and adjacent teeth had no effect on PCL prevalence [18, 19]. One study reported an association between bone level and food impaction [21], and another study found no association between PCL and adjacent tooth mobility of greater than grade I [14]. On the contrary, Pang et al found that the bone level of the adjacent teeth tended to be associated with PCL [13]. One study evaluated implant angulation in relation to the long axis of the adjacent tooth and found no implications on the frequency of food impaction [17].

3.3.9. Implant maintenance

In relation to cleaning habits around the implant, Liang et al reported that more frequent use of the interdental brush (2 times or more per day) was associated with greater prevalence of mesial PCL than less frequent use (1 or less) [14]. On the contrary, Saber et al found the periodontal status, supportive periodontal therapy (SPT) and plaque index on implants had a minimal effect on PCL [20].

3.4. Implications of PCL

The reported implications of PCL were food impaction, consequences on biological variables (bleeding on probing (BoP), mucosal and periodontal health, papillary fill, marginal bone loss, plaque index and caries) and patient dissatisfaction.

3.4.1. Food impaction

Nine studies confirmed that PCL is associated with food impaction [10, 11, 14, 15, 17, 19, 20, 21, 24]. In general, the occurrence and patient awareness of food impaction between implant and natural teeth was frequently observed, and was reported to be about 40–80% [21, 24]. In one study, food impaction was reported in 47% of all proximal embrasure sites [15]. However, with PCL, the chance of food impaction was 2.2 times higher than for intact proximal contacts [15]. According to Varthis et al, 40% of patients with PCL were aware of the presence of food impaction [11]. Similarly, according to Bompolaki et al, 43.8% of patients with PCL reported awareness of food impaction, and the patients with mesial PCL were more aware of food impaction [10]. Liang et al reported more than 3 times increase of food impaction with mesial PCL, and more than 10 times increase of food impaction with distal PCL [14]. Therefore, it appears that food impaction is a very common observation between implant and natural teeth, and the presence of PCL exacerbates the problem of food impaction.

3.4.2. Biological variables

There is some disparity within outcomes of the included studies that evaluated the impact of PCL on biological variables. According to Byun, PCL did not significantly affect the periodontal and peri-implant tissue conditions [15]. Similarly, Jeong and Chang reported no difference in the periodontal and peri-implant mucosal conditions between sites with or without food impaction [21]. The authors of the 2 studies indicated that the majority of their patients were receiving SPT. Likewise, two studies reported no significant association between PCL and BoP, level of papillary fill, and plaque presence [10, 24]. On the other hand, French et al observed a significant trend towards greater mucosal inflammation around implants with PCL [19]. However, there was no indication about the presence or absence of SPT. Saber et al found that PCL was significantly associated with BoP and an increased plaque index on adjacent teeth [20]. The same study reported that the mean marginal bone loss was significantly higher with PCL [20]. However, not all of their patients were undergoing SPT. Nevertheless, due to the cross-sectional nature of the retrospective study, it is not clear if the negative consequences had occurred before or after PCL development. One study reported double the caries incidence for PCL compared with intact proximal contacts [19]. None of the studies found a relation between PCL and the development of peri-implantitis.

3.4.3. Patient satisfaction

Three studies evaluated patient satisfaction with the presence of PCL, and all of them reported a negative rate of patient satisfaction [11, 20, 21]. Specifically, the complaints were associated with the occurrence of food impaction.

4. Discussion

According to the present systematic review, PCL between implant prostheses and adjacent natural teeth is a frequent and inevitable complication of implant treatment, which also increases over the duration of service. The present systematic review attempted to disclose the contributing factors to PCL, and the key factors were the location of the proximal contact and the duration of service. Other factors, such as occlusion, vitality of adjacent teeth, implant location, patient age and splinting had a less obvious relation to PCL. PCL development is multifactorial with several interrelated mechanisms such as mesial drifting of natural teeth, progressive craniofacial growth, and adaptation to occlusal forces [1, 13, 15, 17, 28]. The early loss of proximal contacts (3–6 months) is most likely related to the settling of the prostheses, relaxation of components and adaptation of adjacent teeth to the restored implant [14, 17, 19]. The reported implications of PCL were food impaction, and patient awareness that may lead to dissatisfaction [10, 11, 14, 15, 17, 19, 20, 21, 24]. Biological implications, such as bone loss, peri-implant inflammation, BoP and pocket depth, were not clearly correlated to PCL.

The periodontal ligaments (PDL) around the natural teeth appear to be critical in maintaining the relation between natural teeth, such as proximal and occlusal contacts. Due to the lack of PDL and the ankylotic nature of integrated implants, the implants will behave biomechanically differently from natural teeth, exhibit minimal movement within the bone, and are not susceptible to continuous dentofacial changes. This has been stated by the classical study of Bjork and Skieller, who used reference metal implants to study dentofacial growth in children, and found that while the bone changed through the growth cycle, the implants maintained their original position [30]. An animal investigation confirmed that osseointegrated implants did not move in comparison to adjacent teeth [31]. Several studies on adolescents confirmed that the tooth-implant relation will change with the patients growth, and the implant prostheses may suffer from PCL and infraocclusion [32, 33]. Such dentofacial changes can still occur, while to a lesser extent, in a fully grown individual, and can cause alterations in the relation between the implant prostheses and adjacent natural teeth [1].

The most likely form of dentofacial change that can lead to PCL between implants and natural teeth is the continuous and progressive physiological mesial drifting of the natural teeth [10, 11, 13, 14, 15, 16, 18, 19, 20, 21, 25, 27, 28]. This can be attributed to the direction of functional occlusal forces, the pattern of mandibular movement, and the tendency to load the teeth in an anterior direction [1, 9, 11, 12, 13, 15, 16, 17]. In addition, the drifting of teeth can further be exacerbated with occlusal forces, tooth wear-related dentoalveolar compensation, loss of opposing or adjacent teeth, teeth inclination and occlusal curvature, and interstitial wear between the proximal surfaces [9, 12, 34, 35, 36]. Higher occlusal forces are associated with grinding, tooth wear, mesial drifting of natural teeth, and dentoalveolar compensation, which will further change the positional relation between the implant and the adjacent natural teeth [12, 13, 15, 19]. The included studies did not show a clear influence of

implant location on PCL. However, since the majority of the studies evaluated PCL around posterior implants, it can be speculated that PCL is more noticeable posteriorly and the posterior PCL is associated with more implications [19]. Despite the inconsistent relationship between occlusion and PCL, the impact of occlusion may be relevant if the adjacent teeth had reduced bone and were single rooted, as opposed to multi-rooted teeth that can be more resistant to movement due to occlusal forces [12, 15, 16]. The progressive mesial drifting of natural teeth was further confirmed by the studies that monitored the crowding of the anterior dentition and the reduction of arch length through the lifespan of adult patients [3, 4, 5, 6, 7, 8]. With ankylosed implants, the migration of natural teeth will result predominantly in the opening of the proximal contact between the implants and the natural teeth. In addition, as the migration is expected to be more likely with reduced bone support and teeth mobility, it can be speculated that older patients may suffer from greater PCL than younger patients [16]. However, the limited available literature and conflicting information are not sufficient to draw a clear correlation. On the other hand, the mesial migration of natural dentition does not explain the loss of distal proximal contacts, which was also found to be a common occurrence [23, 27]. Several authors reported that natural teeth are still vulnerable to move in directions other than the mesial migration [1, 9]. Over years of function, natural teeth may move in the buccolingual and vertical directions, and the implant prosthesis may become infraoccluded [1, 9]. In addition, the movement of natural teeth against the ankylotic implant may lead to subsequent proximal wear between the natural teeth and the implant prostheses [17].

While PCL between implants and adjacent natural teeth is not a desirable clinical finding and is thought to lead to biological complications [16], the included studies indicated that PCL between implant prostheses and natural teeth were not necessarily detrimental to biological variables such as soft tissue health, bone level, BoP and plaque index [15, 21, 24]. However, this observation from the included studies could be due to the regular cleaning and placing the patients under routine SPT [15, 21]. A drawback of most of the included studies was the cross-sectional nature of the studies, which does not allow for the identification of the long-term association between PCL and the deterioration of biological variables [15, 21].

Consistently, PCL is associated with food impaction between implant prostheses and adjacent natural teeth, which affects patient satisfaction [10, 11, 14, 15, 17, 19, 20, 21, 24]. It is hypothesized that opening between two adjacent teeth at the proximal surface enhances vertical interproximal food impaction, which is further encouraged by the occlusal morphology of the opposing dentition [14, 15]. However, implant prostheses are more prone to food impaction than natural teeth. In fact, food impaction between implant prostheses and adjacent natural teeth can be 10–20 times more frequent than between natural teeth [1, 14]. Further, food impaction between implants and teeth can occur even with tight proximal contacts [15, 21]. For example, Jeong and Chang reported that 37% of the food impaction sites had tight proximal contacts [21]. Therefore, while PCL can contribute to food impaction, food impaction between implant and natural teeth can be caused by additional factors to the condition of the proximal contacts. Thus, PCL appears to be correlated with food impaction, rather than a sole causative factor of food impaction. Frequently, the embrasure space between the implant and adjacent natural teeth is larger than between natural teeth [21, 22]. In comparison to natural teeth, implant prostheses are distinguished by several features that make them more prone to food impaction, regardless of the tightness of the proximal contacts [15, 21]. This involves the steeper increase in emergence profile and inevitable discrepancy between implant and prosthesis contour, narrower implant cross section in comparison to natural tooth cross section, reduced marginal bone level and soft tissue thickness, enlarged triangle between the natural tooth and implant prosthesis, lack of supra-crestal attachment of soft tissue to implant prosthesis and inevitable reduction of interdental papillae, increased distance between contact point and bone crest, and horizontal and vertical implant position discrepancies in relation to adjacent natural teeth [15, 21]. These features will influence the level of papillary fill, natural contouring and self-cleansing features of implant restoration [21, 22]. Consequently, implant restorations are prone to horizontal food impaction in addition to vertical food impaction [21, 22]. It could be speculated that implant crowns with a square morphology, a gradual increase in emergence profile, wide contact points extending close to the mucosal margin, and reduced embrasure space are less likely to develop food impaction, as opposed to crowns with a triangular and steep profile, and occlusally located proximal contacts [21, 22]. In order to reduce the risk of food impaction, the adjacent natural teeth may need some modifications to widen the future proximal contact buccolingually and occlusogingivally [15, 21]. Other design factors that may influence food impaction are the integrity of the occlusal marginal ridge, and the presence of a plunger cusp in the opposing dentition [14, 15]. However, clearer clinical guidelines on the design of implant restorations and the effect of opposing occlusion are desirable.

Changes in proximal contact are progressive, and in addition to PCL development, the magnitude of opening can increase [9, 13, 17]. It appears that the development of PCL is a natural and long-term adaptation of the implant prosthesis within the dentoalveolar complex. It can also occur at different rates and magnitudes through the years of function [13]. Therefore, the clinician should inform the patient about its likelihood, and the necessity of maintaining a high level of cleanliness around the implant prosthesis [10, 13, 16, 20]. In addition, restored implants should be followed up routinely, and SPT should be provided regularly [13, 16]. It is highly recommended to ensure that the implant restoration is screw-retained to allow for retrievability of the restoration, and the addition of ceramic veneering, or metal solder or laser welding to tighten the proximal contact [11, 13, 15, 21]. In general, as PCL may occur without the awareness of every patient, the clinician may opt to follow a more realistic approach and be driven by patient dissatisfaction and signs of biological or aesthetic complications, rather than the clinical diagnosis of PCL. Specifically, correcting PCL is a clinically and laboratory demanding procedure, and may not necessarily prevent further loss of PCL and food impaction [10, 11, 14, 15, 17, 19, 20, 21, 24, 28]. Tightening the proximal contacts will apply orthodontic forces at the proximal surfaces and may encourage adjacent teeth movement [28], that can even be observed within 3–6 months of service [12, 14, 28]. Some authors suggested the use of a retainer to prevent teeth movement [19, 25]. While retainer use has been shown to have some benefits in reducing PCL rate to 50% in a short-term study [25], its long-term effect, practicality and patient compliance should be confirmed by longer term studies.

The present systematic review is limited by the differences in the follow-up duration among the included studies. Further, the cross-sectional nature of the majority of the studies will prevent the detection of PCL onset and the evaluation of PCL progression. The PCL evaluation techniques of the included studies are subjective and may cause disparity in the reporting of PCL prevalence. For example, the evaluation of proximal contacts by floss insertion may report greater PCL than radiographic evaluation [18]. As a future direction, an agreed method of evaluating proximal contact quality is necessary. From the patient's perspective, it is critical to determine what is acceptable, what is noticeable and what will cause biological and aesthetic complications. In addition, clear information on when intervention is indicated is necessary.

5. Conclusions

Within the limitations of the present systematic review, it can be concluded that PCL development between implant prostheses and natural teeth is a frequent, inevitable and progressive complication. The most prominent contributing factors were the duration of service and the mesial location of the proximal contacts. The most frequent implications of PCL were food impaction and patient dissatisfaction. Biological implications had a less clear association with PCL. Further research is needed to identify the influence of prosthesis design on PCL and food impaction.

Declarations

Author contribution statement

Jaafar Abduo: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Douglas Lau: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Additional information

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