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CLINICAL RESEARCH

Analysis of the risk of interproximal contact loss between adjacent teeth and implant-supported fixed prostheses: A retrospective cross-sectional study

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ABSTRACT

Statement of problem. Food impaction following the placement of an implant-supported restoration is most frequently associated with a high incidence of interproximal contact loss (ICL). Food packing is unpleasant and can cause gingival inflammation and even peri-implant bone resorption. Studies on the various factors that may contribute to the occurrence of ICL are lacking.

Purpose. This retrospective cross-sectional study aimed to collect and analyze data from participants to investigate the incidence of ICL between implant-supported prostheses and adjacent teeth. The study further sought to identify factors influencing ICL, evaluate participants' subjective perceptions of ICL, and explore the relationship between ICL and peri-implant tissue health.

Material and methods. A total of 107 participants with 133 implant-supported fixed prostheses (ISFPs) and 172 interproximal contact relationships, all verified at the time of insertion, were included in this study. A total of 27 factors were assessed in 4 dimensions: participant, ISFP, adjacent tooth, and antagonist. The Spearman correlation analysis, linear-by-linear association chi-squared test, Pearson chi-squared test, and Fisher exact test were used to analyze the factors influencing the ICL (α=.05).

Results. ICL was found to occur as early as 3 months after delivery of an ISFP, with a mean onset of 24 months after delivery. The prevalence of ICL at the participant level was 66.4% and 53.4% at the ISFP level, and the incidence of ICL was higher on the mesial side than on the distal, at 50.5% and 36.9%. Statistically significant differences were found in relation to the contralateral side, root configuration of the distal adjacent tooth, a plunger cusp, and participants' awareness of food impaction (P<.05). Additionally, a significant correlation was found with the delivery time (P<.05).

Conclusions. Delivery time, the contralateral side, root configuration, and an opposing plunger cusp can influence the development of mesial ICL. However, no significant relationship was found between ICL and peri-implant tissue health. Additionally, participants' awareness of food impaction was found to be associated with the occurrence of mesial ICL. (J Prosthet Dent xxxx;xxx:xxx-xxx)

Implant-supported prostheses have been a dependable treatment option for replacing missing teeth with high success rates and patient satisfaction.[1] However, biological, technological, and esthetic concerns still occur with implant-supported prostheses.[2] Chanthasan et al[3] reported that 66.9% of participants subjectively reported food impaction between the implant-supported fixed prostheses (ISFPs) and adjacent natural teeth. Food impaction can be uncomfortable and can also increase the risk of peri-implant mucositis, peri-implantitis, and other disorders since the soft tissues surrounding the implant prostheses are more delicate than those surrounding natural teeth.[4] Wei et al[5] initially revealed the interproximal contact loss (ICL) (Fig. 1A, B) between neighboring natural teeth and the posterior ISFPs. More than half of the participants under examination had ICL, which could appear as soon as 3 months after prosthesis delivery.[5] A high incidence of ICL has been reported, with sites exhibiting ICL being more prone to food impaction compared with sites with tight adjacent contacts.[6,7]

Although the etiology of ICL is yet unknown, the high prevalence of the condition has been reported to be greater than clinically expected, indicating a multifactorial problem.[8]

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Clinical Implications

To achieve a comprehensive restoration, clinicians should consider the health of the mesial, distal, and opposing teeth when restoring missing teeth with implant prostheses. Patients must be informed about the potential for food impaction associated with implant-supported prostheses over time and provide their informed consent prior to restoration. Additionally, clinicians should establish a schedule for follow-up evaluations and emphasize the importance of routine examinations after the delivery of the restoration.

Hypothesized causes of ICL include mesial drifting,[9,10] alveolar bone resorption,[11,12] high occlusal forces,[13] type of prosthesis,[14] differences in physiological mobility between implants and natural teeth,[15] physiological abrasion,[16] and the occlusal design of the prosthesis.[17] When lateral stresses are applied to natural teeth, they move horizontally in the range of 58 to 108 μm. However, osseointegrated implants are considered ankylosed and move horizontally in the range of 10 to 50 μm.[18] In addition, the implants remain in position and do not shift because of alveolar bone remodeling or the proximal displacement of neighboring teeth, which weakens the ISFP-to-natural tooth interface, leading to or accelerating the development of ICL.[8,19] A good tooth-adjacent relationship has an important role in maintaining arch stability and preventing food impaction.[20] Therefore, there is a need to explore risk factors that may lead to ICL and to provide appropriate clinical strategies for the prevention and management of complications.

The purpose of this study was to link the interaction between an ISFP and adjacent teeth and determine whether a particular local factor could contribute to the development of ICL. Additionally, whether participants subjectively detect food impaction in the ICL area and the effects of ICL on the health of the peri-implant tissue were evaluated. The null hypotheses were that ICL would have no effect on the subjective awareness of the participants and that ICL would have no effect on the health of peri-implant tissues.

MATERIAL AND METHODS

The research protocol had been reviewed and approved by the Institutional Review Board of the Ethics Committee of Nanjing First Hospital (Ethics No. KY20240613–05). The study included adults who had received single-unit implant-retained prostheses in the posterior region between March 2018 and April 2024 at the Department of Dentistry, Nanjing First Hospital. Written informed consent was obtained from all participants before their inclusion in the study.

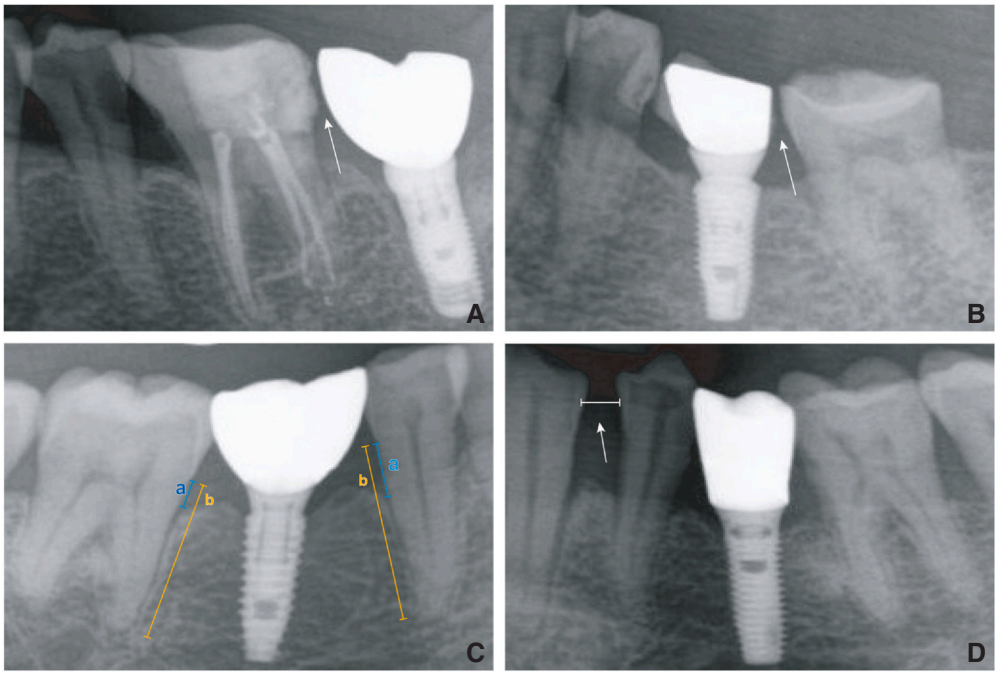

Figure 1. Radiographic analysis of interproximal contact loss between implant-supported fixed prostheses and adjacent teeth. A, ICL of ISFP and mesial adjacent tooth. B, ICL of ISFP and distal adjacent tooth. C, Degree of alveolar bone resorption in mesial and distal sides of implant; (a) distance from cemento-enamel junction to alveolar crest, (b) distance from cemento-enamel junction to root apex, a/b represents extent of bone resorption. D, Contralateral side: mesial space of implant mesial adjacent tooth. *White arrows* showing low-density transmission gap. ICL, interproximal contact loss; ISFPs, implant-supported fixed prostheses.

The inclusion criteria were participants aged 18 years or older who had received implant prostheses for the restoration of missing premolar or molar teeth (from first premolar to second molar) and were able to provide informed consent and fully comprehend the nature of the planned noninterventional long-term follow-up study. Participants were excluded if both the mesial and distal components of the implant prosthesis were implants; if adjacent teeth were directly or indirectly anchored to the implant-supported prostheses; if severe trauma was present at the implant site or adjacent teeth, resulting in extraction of the adjacent teeth; if they were undergoing orthodontic treatment or splinting in the same quadrant; if the prostheses had been removed because of failure or the need for further treatment; or if radiographs and clinical records were unavailable.

This study was divided into 4 areas and data were collected on the participant, ISFP, adjacent tooth, and antagonist. Participant data included the participant's age, sex, medical history (specifically diabetes and smoking habits), unilateral mastication habits, and whether they experienced food impaction in the implant-supported prosthesis area. A history of bruxism was not included in the final statistical analysis, as most participants could not reliably identify whether they had bruxism. ISFP data included the delivery time, prosthesis location, number of implants, type of prosthesis, probing depths (PD), bleeding on probing (BOP), plaque index, and alveolar bone resorption in the mesial and distal aspects of the implant. Radiographic analysis was conducted, with all participants undergoing panoramic radiography. Selected areas were analyzed, as shown in Figure 1C. Adjacent tooth data included the contact surface, contralateral side (Fig. 1D), endodontic treatment (ET), and root configuration of the adjacent teeth. Antagonist data encompassed the opposing dentition, initial occlusal contact, functional occlusal contact, and a plunger cusp. A 200-μm articulating paper (BK 01; Bausch) was used to assess the occlusion of ISFPs.

The interproximal contact of ISFPs was assessed by using waxed dental floss (Reach; Johnson Johnson Healthcare Products). If no resistance was encountered while moving the floss between the ISFP and adjacent tooth surfaces, the contact was classified as open. If the floss encountered moderate to strong resistance, the contact was considered tight. If the floss encountered slight resistance during passage, the contact was classified as loose. An ICL was identified if the contact was deemed open or loose.

All prostheses had been designed according to the specifications provided by the principal investigator (X.W.) and were cement-retained ceramic crowns. The ISFP delivery process included the evaluation of the interproximal contacts to ensure that the dental floss could pass through without catching (contact too tight) or lacking resistance (contact too loose). The contacts were adjusted, if necessary, until the floss encountered appropriate resistance when passing through the proximal area. This process was performed by experienced clinicians and documented in the restoration treatment records.

The investigation was conducted during the participants' routine follow-up visits, with clinical examinations and history taking carried out by the same clinician. Any discrepancies observed during the study were discussed and resolved through consensus.

History-taking data and clinical measurements were recorded in a spreadsheet (Microsoft Excel 2016; Microsoft Corp). A random number generator was used to select the prostheses for analysis when participants had more than one eligible ISFP. Statistical analysis was performed using a statistical software program (IBM SPSS Statistics, v27.0; IBM Corp). Age, delivery time, PD, plaque index, number of implants, and alveolar bone resorption were analyzed using the linear-by-linear association chi-squared test and the Spearman correlation analysis (r_s). The remaining data were analyzed using the Pearson chi-squared test; when more than 20% of cells had an expected count of less than 5, the Fisher exact test was applied (α=.05). Graphs were generated using a software program (GraphPad Prism, v9.5.1; GraphPad Software).

RESULTS

A total of 107 participants (45 men and 62 women) were included in the study, with 133 implants and 133 ISFPs evaluated. Data on 107 mesial contact relationships and 65 distal contact relationships were collected. ICL was identified in 66.4% of the participants, with an incidence of 53.4% at the ISFP level. When examining the contact relationships between each ISFP and the adjacent teeth, the incidence of mesial and distal contact loss was 50.5% and 36.9% (Fig. 2). Basic information of the participants is presented in Table 1.

At the participant level, sex, diabetes and smoking habits, and unilateral mastication habits were not significantly significant in identifying a relationship with ICL. However, a statistically significant association was found between the participant's perception of food impaction and the occurrence of mesial ICL (χ^2=6.120, P=.047) (Table 2).

At the ISFP level, a significant correlation was found between delivery time and the occurrence of mesial ICL (r_s=0.384, P<.001), with a statistically significant increase in ICL incidence over time (χ^2=15.936, P<.001). Figure 3 illustrates the incidence of ICL across different time intervals. The incidence of mesial ICL was higher in the mandibular and molar regions, as well as in participants with multiple implant-supported splinted crowns, although these differences did not reach statistical significance (Table 3).

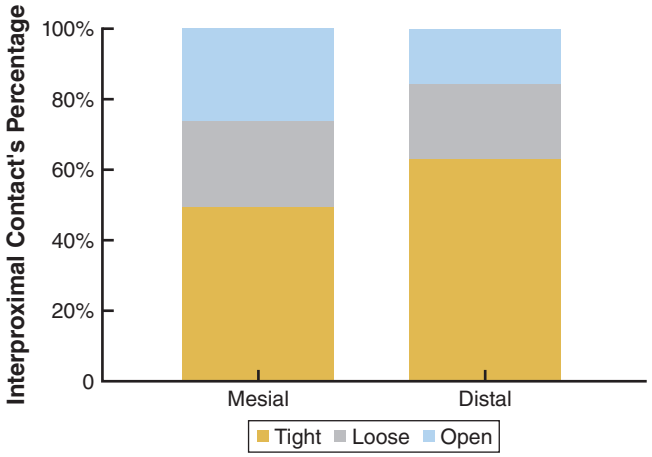

Figure 2. Percentage mesial and distal interproximal contact of implant-supported fixed prostheses. "Tight" considered close contact; "Loose" and "Open" considered interproximal contact loss.

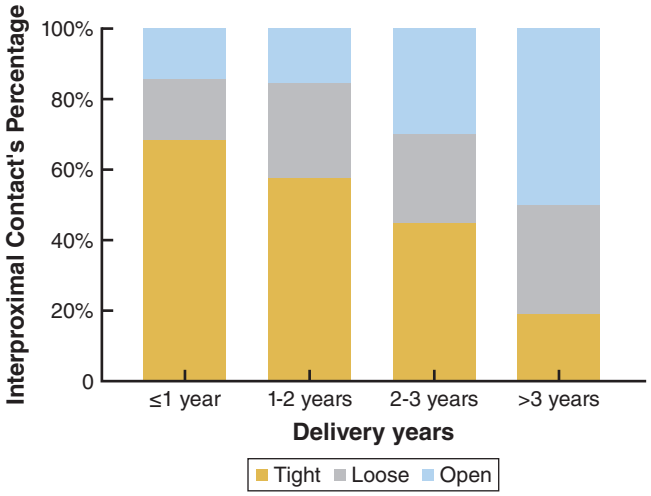

Figure 3. Percentage interproximal contact of implant-supported fixed prostheses at each time interval after delivery. "Tight" considered close contact; "Loose" and "Open" considered interproximal contact loss.

At the level of the adjacent tooth, the contralateral side (χ^2=6.089, *P*=.043) and root configuration of the distal adjacent tooth (χ^2=11.455, *P*=.012) were significantly correlated with the occurrence of mesial ICL (Table 4). At the level of the antagonist, the presence of plunger cusps significantly increased the incidence of mesial ICL (χ^2=6.746, *P*=.034) (Table 5).

Table 1. Participant information and incidence of interproximal contact loss

Characteristics of Participants			
Item	**n**	**ICL (n)**	**Prevalence(%)**
Participant number	107	71	66.4
Age	55 ±12 (range 21 to 85)	——	——
Sex ratio (Men/Women)	45/62	——	——
Mean follow-up months	24 ±16 (range 2 to 75)	——	——
Implant number	133	——	——
Implant-supported fixed prostheses	133	71	53.4
Single crown	81	——	——
Splinted crown	26	——	——
No. of proximal contacts	172	78	45.3
Mesial	107	54	50.5
Distal	65	24	36.9
No conscious food impaction	54	22	68.8

Table 2. Participant-level risk assessment of mesial interproximal contact loss

Participant Characteristics	**Mesial Contact Tightness Level**						
	Tight		**Loose**		**Open**		***P***
	n	%	n	%	n	%	
Age							
Younger than mean (55.74y)	26	48.1	16	29.6	12	22.2	.751
Older than mean (55.74y)	27	50.9	10	18.9	16	30.2	
Sex							
Woman	32	51.6	12	19.4	18	29.0	.355
Man	21	46.7	14	31.1	10	22.2	
Diabetes history							
No	48	50.5	22	23.2	25	26.3	.671
Yes	5	41.7	4	33.3	3	25.0	
Smoking							
Nonsmoker	45	48.4	22	23.7	26	28.0	.654
Smoker	8	57.1	4	28.6	2	14.3	
Unilateral mastication habit							
Ipsilateral	17	50.0	8	23.5	9	26.5	.859
Contralateral	17	56.7	7	23.3	6	20.0	
Both sides	19	44.2	11	25.6	13	30.2	
Food impaction perception							
Unrecognized	32	59.3	8	14.8	14	25.9	.047*
Recognized	21	39.6	18	34.0	14	26.4	

Table 3. ISFP-level risk assessment of mesial interproximal contact loss

Implant Prosthesis	Mesial Contact Tightness Level						
	Tight		Loose		Open		*P*
	n	%	n	%	n	%	
Delivery time							
≤1 year	24	68.6	6	17.1	5	14.3	< .001*
1–2 years	15	57.7	7	26.9	4	15.4	
2–3 years	9	45.0	5	25.0	6	30.0	
> 3 years	5	19.2	8	30.8	13	50.0	
Location of prosthesis							
Maxilla	27	54.0	9	18.0	14	28.0	.362
Mandible	26	45.6	17	29.8	14	24.6	
Premolar	15	55.6	6	22.2	6	22.2	.762
Molar	38	47.5	20	25.0	22	27.5	
Number of implants							
1 implant	44	54.3	19	23.5	18	22.2	.058
Multiple implants	9	34.6	7	26.9	10	38.5	
Prosthesis type							
Single crown	44	54.3	19	23.5	18	22.2	.163
Splinted crown	9	34.6	7	26.9	10	38.5	
PD							
≤3 mm	20	54.1	8	21.6	9	24.3	.334
3–5 mm	17	51.5	9	27.3	7	21.2	
> 5 mm	16	43.2	9	24.3	12	32.4	
BOP							
BOP(-)	27	55.1	10	20.4	12	24.5	.542
BOP(+)	26	44.8	16	27.6	16	27.6	
Plaque index							
0	4	57.1	2	28.6	1	14.3	.142
1	15	60.0	3	12.0	7	28.0	
2	16	51.6	10	32.3	5	16.1	
3	18	40.9	11	25.0	15	34.1	
Bone level of mesial							
≤1/2	33	55.0	16	26.7	11	18.3	.065
> 1/2	20	42.6	10	21.3	17	36.2	
Bone level of distal							
≤1/2	40	47.6	21	25.0	23	27.4	.463
> 1/2	13	56.5	5	21.7	5	21.7	

BOP, bleeding on probing; PD, probing depths.

Table 4. Adjacent tooth-level risk assessment of mesial interproximal contact loss

Adjacent Tooth	Mesial Contact Tightness Level						
	Tight		Loose		Open		*P*
	n	%	n	%	n	%	
Mesial contact surface							
Natural tooth	44	49.4	22	24.7	23	25.8	.554
Composite resin	2	50.0	2	50.0	0	0.0	
Artificial crown	7	50.0	2	14.3	5	35.7	
Contralateral side							
No spacing	49	53.8	22	24.2	20	22.0	.043*
Spacing	4	25.0	4	25.0	8	50.0	
Mesial ET							
No	48	51.6	24	25.8	21	22.6	.114
Yes	5	35.7	2	14.3	7	50.0	
Distal ET							
No	35	59.3	13	22.0	11	18.6	.509
Yes	5	83.3	0	0.0	1	16.7	
Root configuration of mesial adjacent tooth							
Single root	43	51.8	19	22.9	21	25.3	.672
Multiple roots	10	41.7	7	29.2	7	29.2	
Root configuration of distal adjacent tooth							
Distal-extension absence	13	31.0	13	31.0	16	38.1	.012*
Single root	2	40.0	2	40.0	1	20.0	
Multiple roots	38	62.3	12	19.7	11	18.0	

ET, endodontic treatment.

The periodontal PD, plaque index, BOP, and bone resorption were not statistically significant enough to directly identify a relationship between periodontal condition and ICL. All factors significantly associated with the occurrence of mesial ICL are listed, with their incidences of ICL presented in Figure 4. In the analysis of distal ICL, no factors were found to be significantly associated with its occurrence (P>.05) (Tables 6–9).

Table 5. Antagonist-level risk assessment of mesial interproximal contact loss

Antagonist	Mistal Contact Tightness Level						
	Tight		Loose		Open		*P*
	n	%	n	%	n	%	
Opposing dentition							
Natural tooth	40	48.8	22	26.8	20	24.4	.762
Fixed denture	12	50.0	4	16.7	8	33.3	
Removable denture	1	100.0	0	0.0	0	0.0	
Initial occlusal contact							
No	22	64.7	7	20.6	5	14.7	.078
Yes	31	42.5	19	26.0	23	31.5	
Functional occlusal contact							
No	4	57.1	0	0.0	3	42.9	.305
Yes	49	49.0	26	26.0	25	25.0	
Plunger cusp							
No	45	52.9	16	18.8	24	28.2	.034*
Yes	8	36.4	10	45.5	4	18.2	

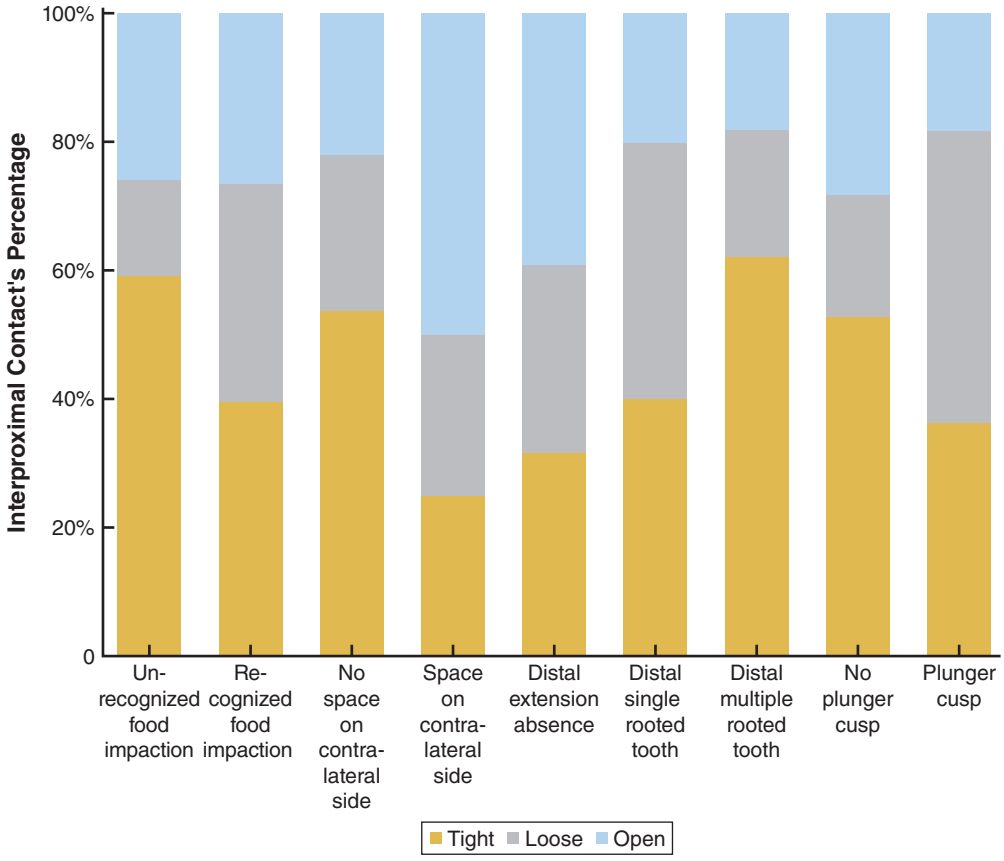

Figure 4. Factors determined to be associated with interproximal contact loss. ET, endodontic treatment of adjacent teeth.

DISCUSSION

Participants' subjective perception of food impaction was significantly associated with the occurrence of mesial ICL. However, no significant association was found for distal ICL, leading to partial rejection of the null hypothesis that ICL would have no effect on participants' subjective awareness. Notably, 68.8% of participants with ICL did not report any obvious symptoms (Table 1), suggesting that ICL can be asymptomatic to a certain extent, highlighting the importance of regular clinical follow-up after the delivery of ISFPs.

This study assessed the health of peri-implant tissues on both the mesial and distal sides of the implant. The results indicated that the observed differences were not sufficiently significant to establish a relationship between the periodontium and the development of ICL, consistent with Ko et al.[21] Consequently, the null hypothesis that ICL would have no effect on the health of peri-implant tissues was not rejected. However, this

Table 6. Participant-level risk assessment of distal interproximal contact loss

Participant Characteristics	Distal Contact Tightness Level						P
	Tight		Loose		Open		
	n	%	n	%	n	%	
Age							
Younger than mean (55.4y)	23	65.7	9	25.7	3	8.6	.274
Older than mean (55.4y)	18	60.0	5	16.7	7	23.3	
Sex							
Woman	25	64.1	8	20.5	6	15.4	.969
Man	16	61.5	6	23.1	4	15.4	
Diabetes history							
No	38	64.4	11	18.6	10	16.9	.191
Yes	3	50.0	3	50.0	0	0.0	
Smoking							
Nonsmoker	36	64.3	12	21.4	8	14.3	.774
Smoker	5	55.6	2	22.2	2	22.2	
Unilateral mastication habit							
Ipsilateral	12	63.2	5	26.3	2	10.5	.875
Contralateral	12	57.1	5	23.8	4	19.0	
Both sides	17	68.0	4	16.0	4	16.0	
Food impaction perception							
Unrecognized	22	64.7	8	23.5	4	11.8	.681
Recognized	19	61.3	6	19.4	6	19.4	

Table 7. ISFP-level risk assessment of distal interproximal contact loss

Implant Prosthesis	Distal Contact Tightness Level						P
	Tight		Loose		Open		
	n	%	n	%	n	%	
Delivery time							
≤1 year	12	54.5	8	36.4	2	9.1	.230
1–2 years	8	50.0	4	25.0	4	25.0	
2–3 years	9	75.0	0	0.0	3	25.0	
>3 years	12	80.0	2	13.3	1	6.7	
Location of prosthesis							
Maxilla	17	54.8	8	25.8	6	19.4	.418
Mandible	24	70.6	6	17.6	4	11.8	
premolar	15	62.5	6	25.0	3	12.5	.811
Molar	26	63.4	8	19.5	7	17.1	
Number of implants							
1 implant	38	61.3	14	22.6	10	16.1	.218
Multiple implants	3	100.0	0	0.0	0	0.0	
Prosthesis type							
Single crown	38	61.3	14	22.6	10	16.1	.737
Splinted crown	3	100.0	0	0.0	0	0.0	
PD							
≤3mm	18	66.7	6	22.0	3	11.1	.631
3–5mm	14	60.9	4	17.4	5	21.7	
>5 mm	9	60.0	4	26.7	2	13.3	
BOP							
BOP (-)	21	67.7	5	16.1	5	16.1	.597
BOP (+)	20	58.8	9	26.5	5	14.7	
Plaque index							
0	3	60.0	2	40.0	0	0.0	.733
1	7	46.7	6	40.0	2	13.3	
2	15	68.2	3	13.6	4	18.2	
3	16	69.6	3	13.0	4	17.4	
Bone level of the mesial							
≤1/2	27	64.3	9	21.4	6	14.3	.738
>1/2	14	60.9	5	21.7	4	17.4	
Bone level of the distal							
≤1/2	27	64.3	9	21.4	6	14.3	.738
>1/2	14	60.9	5	21.7	4	17.4	

BOP, bleeding on probing; PD, probing depths.

does not imply that periodontal health should be disregarded. Persson et al[22] reported that teeth with poor periodontal health are susceptible to unbalanced forces and have a greater degree of mobility than healthy teeth even under the same occlusal pressure, which can lead to food impaction.

The present study examined the incidence of ICL and the factors influencing it from 4 perspectives. When analyzing the impact of participant characteristics and mastication habits on ICL, no statistically significant differences were observed ($P>.05$). Similarly, previous clinical studies[9,13,23] have reported no significant effect

Table 8. Adjacent tooth-level risk assessment of distal interproximal contact loss

Adjacent Tooth	Distal Contact Tightness Level						P
	Tight		Loose		Open		
	n	%	n	%	n	%	
Mesial contact surface							
Unrestored tooth	37	68.5	11	20.4	6	11.1	.061
Composite resin	2	66.7	0	0.0	1	33.3	
Artificial crown	2	25.0	3	37.5	3	37.5	
Contralateral side							
No spacing	35	61.4	13	22.8	9	15.8	.865
Spacing	6	75.0	1	12.5	1	12.5	
Mesial ET							
No	38	64.4	12	20.3	9	15.3	.701
Yes	3	50.0	2	33.3	1	16.7	
Distal ET							
No	39	66.1	11	18.6	9	15.3	.103
Yes	2	33.3	3	50.0	1	16.7	
Root configuration of mesial adjacent tooth							
Single root	34	61.8	13	23.6	8	14.5	.799
Multiple roots	6	66.7	1	11.1	2	22.2	
Root configuration of distal adjacent tooth							
Single root	3	60.0	1	20.0	1	20.0	.956
Multiple roots	38	63.3	13	21.7	9	15.0	

ET, endodontic treatment.

Table 9. Antagonist-level risk assessment of distal interproximal contact loss

Antagonist	Distal Contact Tightness Level						P
	Tight		Loose		Open		
	n	%	n	%	n	%	
Opposing dentition							
Natural tooth	33	67.3	9	18.8	7	14.3	.562
Fixed denture	8	50.0	5	31.3	3	18.8	
Initial occlusal contact							
No	15	60.0	7	28.0	3	12.0	.303
Yes	26	65	7	17.5	7	17.5	
Functional occlusal contact							
No	2	50.0	2	50.0	0	0.0	.315
Yes	39	63.9	12	19.7	10	16.4	
Plunger cusp							
No	34	68.0	9	18.0	7	14.0	.298
Yes	7	46.7	5	33.3	3	20.0	

of age, sex, diabetes, smoking, or unilateral mastication habits on the occurrence of ICL.

At the ISFP level, the earliest occurrence of ICL was observed 3 months after prosthesis delivery, with a mean onset at 24 months, consistent with French et al.[24] This timing may be attributed to the mesial movement of adjacent natural teeth and the ongoing remodeling of the alveolar bone. Initially, occlusion was designed to be implant-protected at the time of prosthesis delivery.[25] However, the adjacent teeth are subjected to increased occlusal forces, and, in the occlusal state, the natural teeth generate a mesial force that is 5 times greater than the distal force.[10,26] Furthermore, the total arch length in both the maxilla and mandible decreases by approximately 1.0 mm and 0.8 mm over a span of 20 years, corresponding to a mesial movement of natural teeth of approximately 0.005 mm per year in the maxilla and 0.004 mm in the mandible.[12]

At the level of the adjacent tooth, the presence of a contralateral side was found to weaken the resistance to mesial tooth movement, contributing to the development of ICL.[27] Koori et al[28] reported that the ET of implant-adjacent teeth increased the incidence of ICL. However, in the present study, no statistically significant difference was found between ET and the incidence of ICL ($P>.05$). Regarding the root configuration of the adjacent tooth, the present results suggested that the root configuration of the distal adjacent tooth may have a greater influence on the occurrence of mesial ICL. Specifically, implants adjacent to the multirooted tooth in the distal region may help reduce the incidence of mesial ICL to some extent. Examining the mesial contact surface of ISFPs, Loomans et al[29] suggested that natural teeth undergo slow, physiological abrasion of the adjacent surfaces in the functional state and that the poor abrasion resistance of composite resins, coupled with the technical sensitivity of intraoral treatment, tends to result in a decrease in the tightness of the adjacent contacts. However, in the present study, no statistically significant difference was found between the contact surface of ISFPs and the incidence of ICL ($P>.05$).

A plunger cusp may wedge between the opposing teeth during occlusion, resulting in food impaction and, over time, forcing ICL. The present study did not identify any significant effects of the opposing dentition, initial occlusal contact, or functional occlusal contact on ICL, consistent with Anita et al.[12] It has been suggested that softer materials, such as those used in removable prostheses on the opposing side of ISFPs, may reduce occlusal pressure, thereby helping to decrease the incidence of ICL.[28] However, the number of participants with removable partial dentures (RPDs) in this study was insufficient to evaluate this phenomenon.

The present study also evaluated the impact of various factors on distal ICL in ISFPs. However, no statistically significant differences were found. Previous studies have suggested that factors such as occlusal interference, suboptimal size and shape of the distal surface, and occlusal design issues could contribute to the development of distal ICL.[30,31]

ICL compromises the integrity of the dental arch, leading to increased patient discomfort and a higher treatment burden.[8,9,23] Enhancing treatment predictability can be achieved by considering controllable factors related to the ISFP, the adjacent teeth, and the opposing dentition. Clinicians should carefully select the implant treatment plan and implant timing, use digital navigation, restore the adjacent tooth and the occlusal relationship appropriately, and implement implant-protected occlusion with reasonable control. Effective preoperative communication with patients and close supervision of oral hygiene practices are essential. Regular reviews of ISFPs should be conducted, and prosthetic replacement should be considered when necessary. These measures will increase treatment costs, and informed consent must be provided before any surgical procedure.[8]

Limitations of the study included that ICL is a multifactorial condition, and collecting participant-level data presents challenges in controlling for confounding variables, thereby limiting the ability to identify the true causal factors. Additionally, some patients did not adhere fully to the recommended follow-up schedule after implant-supported restoration, and early patient records were incomplete or unavailable, leading to a limited sample size. Furthermore, although a broad range of potential risk factors were examined, no statistically significant factors were identified for the development of distal ICL. Future research should aim to further elucidate the risk factors for ICL, particularly distal ICL, through broader parameters and prospective, controlled studies. Additionally, using 3D models to quantitatively assess ICL size could provide valuable insights.

CONCLUSIONS

Based on the findings of this clinical study, the following conclusions were drawn:

1. Mesial ICL following ISFP delivery became more prevalent over time, with occurrence as early as 3 months after the definitive prosthesis.
2. Factors such as the contralateral side, missing or single-rooted distal tooth, and a plunger cusp were associated with an increased incidence of mesial ICL ($P<.05$).
3. The participant's subjective perception of ICL was significantly correlated with the occurrence of mesial ICL ($P<.05$).
4. No significant relationship was found between the development of ICL and peri-implant tissue conditions. PD, BOP, plaque index, or the degree of bone resorption on the mesial and distal sides did not affect ICL development ($P>.05$).

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Jiaping Wang: Conceptualization, Methodology, Software, Validation, Writing- reviewing and editing. **Juan Lin**: Data curation, Writing- original draft preparation. **Yan Chen**: Visualization, Investigation. **Xin Wu**: Supervision, Conceptualization, Methodology, Software, Validation, Writing- reviewing and editing.

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