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Original Article

The mesial–mesial/distal–distal (MM-DD) occlusal adjustment technique: A 2–21.5-year retrospective study on preventing open contacts in posterior implant restorations

Chiun-Lin Steven Liu [a,b,c,d], Shih-Cheng Wen [e], Ching-Jung Chang Chien [f], Je-Kang Du [b,g*]

[a] School of Dental Medicine, University of Pennsylvania, Philadelphia, PA, USA
[b] School of Dentistry, College of Dental Medicine, Kaohsiung Medical University, Kaohsiung, Taiwan
[c] Main Line Dental Implant Center, Private Practice, Berwyn, PA, USA
[d] Dr. Morton Amsterdam Museum, PA, USA
[e] School of Dentistry, College of Oral Medicine, Taipei Medical University, Taipei, Taiwan
[f] Kande Dental Clinic Private Practice, Taipei, Taiwan
[g] Department of Dentistry, Kaohsiung Medical University Hospital, Kaohsiung, Taiwan

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Mesial drift;
Implant prosthodontic

Abstract *Background/purpose:* Open contacts adjacent to posterior dental implants are a common clinical complication, often resulting in food impaction, discomfort, and periodontal deterioration. This study aimed to evaluate the long-term clinical effectiveness of the mesial–mesial/distal–distal (MM-DD) occlusal adjustment technique in preventing open contacts adjacent to posterior implant restorations.
Materials and methods: This retrospective study analyzed 124 single-tooth posterior implants in 100 patients over a 2–21.5-year follow-up period. The MM-DD technique involved selectively modifying occlusal contacts on the mesial occlusal surface of the mesial adjacent tooth and the distal occlusal surface of the distal adjacent tooth to influence mesial tooth movement and maintain proximal contact with implant restorations. Clinical and radiographic data were assessed for contact integrity, food impaction, discomfort, bone levels, and other outcomes. A control group with conventional occlusal adjustment was included for comparison.
Results: The MM-DD group demonstrated a significantly lower incidence of open contacts (2.7 %) compared to the control group (46.7 %, $P < 0.001$). Patients treated with the MM-DD

* Corresponding author. School of Dentistry, Kaohsiung Medical University, No.100, Shih-Chuan 1st Road, Kaohsiung 80708, Taiwan.
E-mail address: dujekang@gmail.com (J.-K. Du).

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technique reported reduced food impaction and lower discomfort scores, with less proximal bone loss around adjacent teeth. Kaplan—Meier analysis showed high rates of long-term contact stability in the MM-DD group, with 96.2 % of contacts remaining intact at 15 years.
Conclusion: With its straightforward application, sound biological foundation, and minimal need for specialized equipment, the MM-DD technique presents a practical and effective solution for preserving proximal contact in posterior implants and is well-suited for widespread adoption in daily dental practice.

Introduction

Dental implants are widely regarded as the standard of care for replacing missing posterior teeth due to their high survival rates, load-bearing capacity, and favorable esthetic and functional outcomes.[1] Despite their biomechanical advantages, implant-supported prostheses are prone to specific complications that differ from those affecting natural teeth. One frequently reported issue is the progressive loss of interproximal contact between the implant crown and adjacent natural teeth, especially in posterior sites.

The incidence of open proximal contacts in posterior implant restorations has been reported to range from 34 % to 66 %, with mandibular implants being more susceptible.[2–4] This phenomenon is attributed to the lack of periodontal ligament in implants, which prevents natural movement, while adjacent teeth continue to migrate mesially due to functional occlusal forces and physiologic drift.[3,5] Resulting contact loss can lead to food impaction, gingival inflammation, interproximal bone loss, caries formation, and decreased patient satisfaction.[6–8]

Several restorative techniques, including splinted restorations, periodic adjustments, and over-contoured proximal surfaces, have been proposed to manage or delay contact loss.[9,10] However, these solutions are often reactive, require long-term maintenance, and have not demonstrated consistent long-term efficacy. There remains a need for a preventive, evidence-based strategy that addresses the biomechanical etiology of contact loss.

The mesial—mesial/distal—distal (MM-DD) occlusal adjustment technique was developed as a proactive approach to mitigate open contact development. The technique involves specific occlusal adjustments on the adjacent natural teeth to facilitate their mesial movement toward the implant crown, thereby preserving contact. This retrospective study evaluates the long-term clinical outcomes of the MM-DD technique over a follow-up period of up to 21.5 years, with a focus on proximal contact integrity, patient-reported symptoms, and peri-implant bone stability.

Materials and methods

Study design and patient selection

This retrospective study analyzed clinical data from patients who received posterior dental implant restorations at a private dental practice between July 2000 and January 2022. This study was approved by the Institutional Review Board of Kaohsiung Medical University Hospital (KMUHIRB-E (I)-20250,203).

Inclusion criteria were as follows

1. Patients aged 24 years or older.
2. Single-tooth posterior implant restorations with natural teeth.
3. Adjacent to both the mesial and distal aspects or mesial aspects only.[1,4]
4. Implant restorations in function for a minimum of 2 years and up to 21.5 years.[5,11]
5. Complete clinical and radiographic records available for review.
6. Regular maintenance appointments (at least once annually).[6]

Exclusion criteria included

1. Patients with severe periodontal disease (clinical attachment loss >6 mm).[7]
2. Patients with parafunctional habits not managed by occlusal appliances.[12,13]
3. Implants adjacent to other implant restorations.
4. Patients with systemic conditions affecting bone metabolism.
5. Implants with severe angulation (>30° from ideal).[14,15]
6. Inadequate follow-up records.
7. Significant modifications to the occlusal scheme after implant restoration.[16]
8. History of orthodontic treatment after implant restoration.[17]

Sample size and patient demographics (Table 1)

The study included 100 patients (52 females, 48 males) who received a total of 124 single-unit posterior implant crowns. The distribution of implants was as follows: 28 maxillary premolars, 32 maxillary molars, 18 mandibular premolars, and 46 mandibular molars. Across all cases, 124 mesial contact surfaces and 110 distal contact surfaces were evaluated. Patient age ranged from 24 to 84 years, with a mean age of 54.2 ± 12.1 years.

All implants were placed in healed alveolar ridges, delayed implant placement or immediate implant placement (IIP). Implant dimensions ranged from 3.5 to 6.0 mm in diameter and 8.5—13 mm in length. Restorations were delivered as single-unit screw- or cement-retained crowns, fabricated using porcelain-fused-to-metal, zirconia, or lithium disilicate materials.

Surgical and prosthetic protocols

All implants were placed by the same clinician (CLL) using a standardized surgical protocol.[15,18] Implants from three major manufacturers were used, all with moderately rough surfaces. Implant diameters ranged from 3.5 mm to 6.0 mm, and lengths ranged from 8.5 mm to 13 mm.[11]

Prosthetic procedures were performed following a standardized protocol.[19,20] After osseointegration was confirmed (5—6 months post-implant placement), final impressions were taken using a polyvinyl siloxane material in a custom tray or digital impression. All implant restorations were screw-retained or cement-retained (using resin-modified glass ionomer cement) depending on clinical requirements.[20,21] Material selection for the final restorations included porcelain-fused-to-metal, lithium disilicate, and zirconia.[22,23]

Dr. Liu's MM-DD occlusal adjustment technique

The MM-DD (mesial—mesial/distal—distal) occlusal adjustment technique was applied at the time of crown delivery as follows (Figs. 1—9):

Occlusal contacts were recorded using 42 μm articulating paper (2 layers of 21 μm articulating paper) in maximum intercuspation and during lateral and protrusive mandibular movements.[12]

1. On the mesial adjacent tooth, occlusal contact on the mesial occlusal surface was selectively reduced, preserving contact at the central fossa and distal marginal ridge.
2. On the distal adjacent tooth, occlusal contact on the distal occlusal surface was selectively reduced, maintaining contact at the central fossa and mesial marginal ridge.
3. The implant crown was adjusted to achieve primary occlusal contact at the central fossa and secondary contacts approximately 1 mm inside the marginal ridges.[12,24]
4. Occlusion was verified with articulating paper and refined as needed to ensure stability.[12]

For control purposes, a subset of posterior implant restorations received conventional occlusal adjustment without the MM-DD technique during the first five years of the study period (2000—2005). These cases were analyzed separately to compare outcomes.

This technique aims to create functional occlusal relief zones that accommodate physiologic mesial drift, as described in prior studies.[25,26]

Control group and group allocation

A control group was identified from cases treated between 2000 and 2005, in which conventional occlusal adjustment was performed without MM-DD modifications. Patients were categorized into two groups:

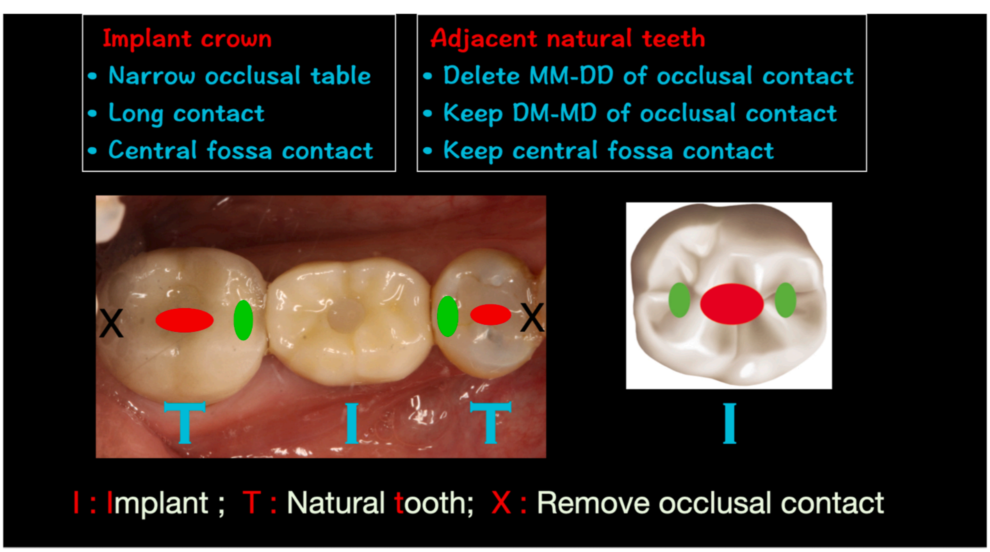

Figure 1 (1) Remove the occlusal contact at the mesial occlusal surface of the mesial adjacent tooth (keep central fossa and distal occlusal contact). (2) Remove the occlusal contact at the distal occlusal surface of the distal adjacent tooth (keep central fossa an mesial occlusal contact). (3) Implant crown: primary occlusal contact at central fossa, secondary occlusal contact at 1 mm inside of marginal ridge.
*MM-DD: Mesial—mesial/distal—distal.
DM-MD: Distal-mesial/mesial-distal.
I: Implant T: Natural teeth X: Remove occlusal contact.

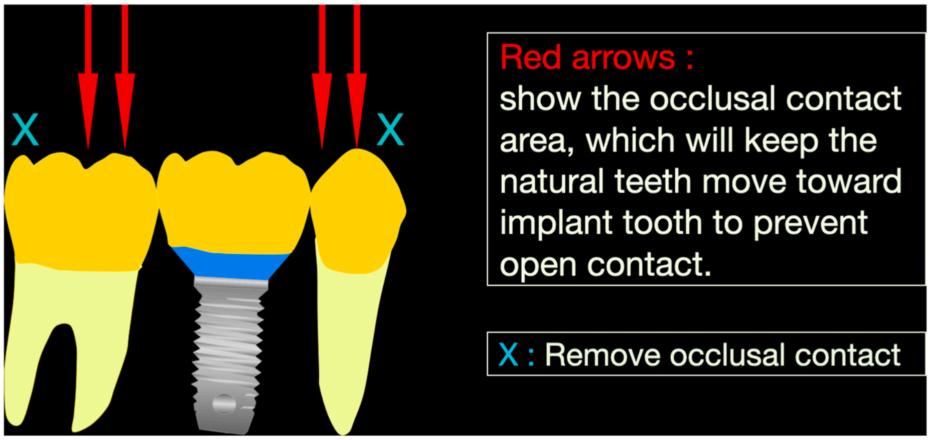

Figure 2 (1) Red arrows show the occlusal contact area, which will keep the natural teeth move toward implant teeth to prevent open contact. (2) X: remove the occlusal contact at the mesial occlusal surface of the mesial adjacent tooth and remove the occlusal contact at the distal occlusal surface of the distal adjacent tooth.

Figure 3 Example case 1: (2 years follow-up). 50 y/o female. Tooth 26: immediate implant placement, implant was placed at palatal root area. Titanium-base screw-retained zirconia crown was restored 6 months after surgery. Both day 1 and 2 years follow-ups show tight mesial and tight distal contact relationships radiographically and clinically.

MM-DD group: Received the MM-DD occlusal adjustment at crown delivery using 40–50 μm articulating paper.[27]

Control group: Underwent conventional occlusal adjustment without targeted mesial or distal contact relief.

In the MM-DD group, implant occlusion was adjusted to provide firm central fossa contact on the crown and light axial contact on adjacent teeth, minimizing lateral force transmission to the implant structure.[28,29]

Outcome measures

Primary outcome measures included:
Proximal contact integrity was evaluated using dental floss and 21 μm articulating paper to assess the quality of interproximal engagement between implant restorations and adjacent natural teeth.[2,20] Contacts were classified into three categories based on clinical resistance during flossing and visual inspection: tight contacts exhibited notable resistance to floss passage, indicating firm interproximal engagement; normal contacts allowed floss to pass with light resistance, reflecting physiologic contact tightness; and open contacts showed no resistance, often accompanied by visible spacing or patient-reported food impaction.

Patient-reported outcomes, including food impaction and discomfort (visual analog scale and 5-point Likert satisfaction score)

Radiographic assessment of marginal bone levels around implants and adjacent teeth.

Follow-up protocol and assessment

Patients were examined at 2 weeks, 3 months, and 6 months post-restoration, followed by annual reviews. The following parameters were assessed at each visit:

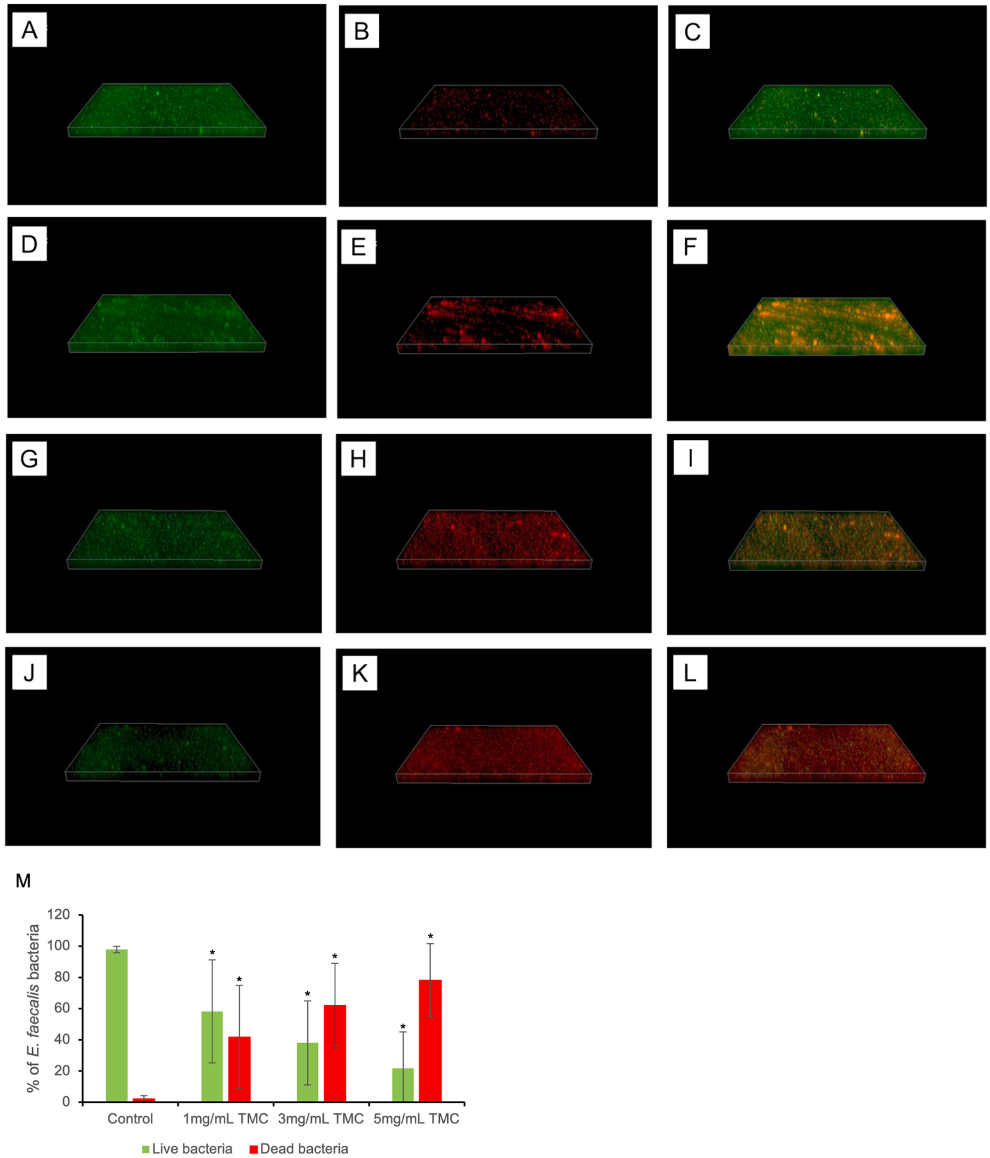

Figure 4 Example case 2: (3 years follow-up). 65 y/o female. Tooth 15: immediate implant placement, implant was placed at palatal root area. Titanium-base screw-retained zirconia crown was restored 6 months after surgery. Both day 1 and 3 years follow-ups show tight mesial contact relationships radiographically and clinically.

Proximal contact integrity was assessed using dental floss and 21 μm articulating paper to evaluate interproximal contact tightness. Contacts were categorized as tight when floss passage encountered significant resistance, normal when floss passed with light resistance, and open when no resistance was present, often accompanied by visible spacing or patient-reported food impaction.[3,4]

Standardized periapical radiographs were taken annually for all implant sites. These radiographs were used to monitor crestal bone levels around implants and adjacent teeth, evaluate changes in proximal bone height over time, and identify the presence of periapical or peri-implant pathology, such as radiolucent lesions, bone loss, or other signs of disease progression.[4,30]

Clinical periodontal parameters were recorded at each follow-up visit to assess peri-implant and periodontal health. These included probing depths around the implant and adjacent natural teeth, bleeding on probing, presence of gingival recession, and any signs of increased mobility of the adjacent teeth.[7,30]

Patient-reported outcomes were also recorded to evaluate subjective experiences following implant restoration. Patients were asked to report the presence or absence of food impaction. Discomfort was measured using a visual analog scale ranging from 0 to 10, where 0 indicated no discomfort and 10 represented severe discomfort. Overall satisfaction with the implant restoration was recorded using a 5-point Likert scale, with higher scores indicating greater satisfaction.[31]

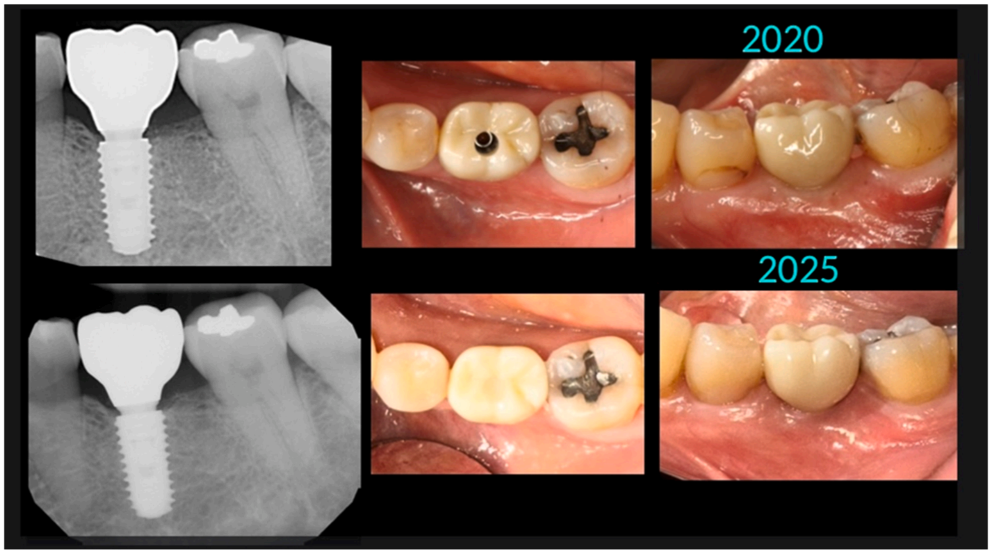

Figure 5 Example case 3: (5 years follow-up). 55 y/o female. Tooth 36: delayed implant placement. Titanium-base screw-retained zirconia crown was restored 5 months after surgery. Both day 1 and 5 years follow-ups show tight mesial and tight distal contact relationships radiographically and clinically

Figure 6 Example case 4: (11 years follow-up). 40 y/o male. Tooth 26: immediate implant placement. Implant was placed at septum area. Titanium custom abutment and cement-retained zirconia crown was restored 6 months after surgery. Both day 1 and 11 years follow-ups show tight mesial and tight distal contact relationships radiographically and clinically.

Statistical analysis

Data were analyzed using statistical software (SPSS version 26.0, IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated for all variables. The Kaplan–Meier method was used to analyze the survival rate of proximal contacts (time to open contact development). Chi-square tests and Fisher's exact tests were used to compare categorical variables between groups. Independent t-tests and Mann–Whitney U tests were used for continuous variables, depending on data distribution. Multivariate regression analysis was performed to identify factors associated with open contact development. Statistical significance was set at $P < 0.05$. Post-hoc power analysis indicated that the study had >80 % power to detect a difference of ≥20 % in open contact incidence between groups ($\alpha = 0.05$).

Results

Incidence of open contacts

MM-DD technique group (Table 2)
Among the 124 posterior implants evaluated, 75 restorations received MM-DD occlusal adjustment while 49 served as conventional control cases. At final evaluation, only 2

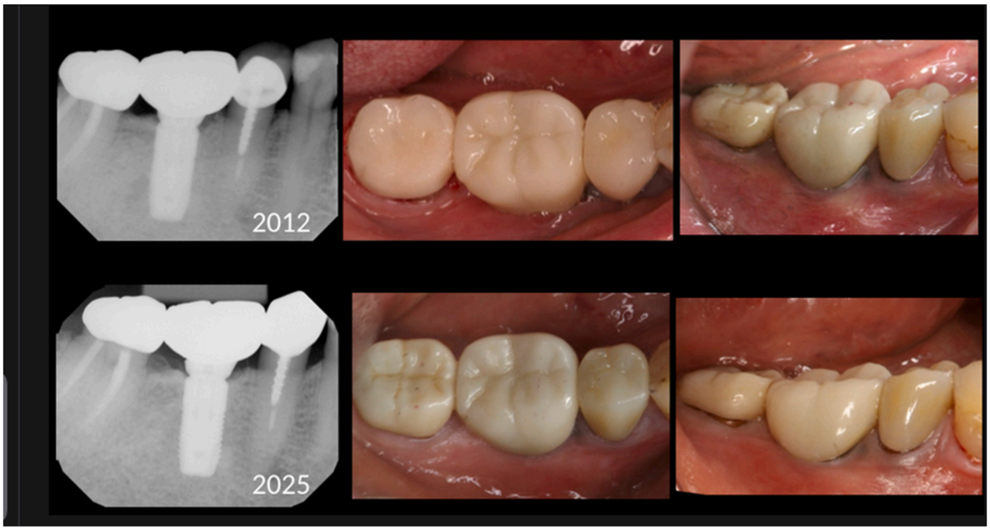

Figure 7 Example case 5: (13 years follow-up). 60 y/o female. Tooth 46: immediate implant placement. Implant was placed at septum area. Titanium custom abutment and cement-retained zirconia crown was restored 5 months after surgery. Both day 1 and 13 years follow-ups show tight mesial and tight distal contact relationships radiographically and clinically.

Figure 8 Example case 6: (15 years follow-up). 47 y/o female. Tooth 26: immediate implant placement. Implant was placed at septum area. Titanium custom abutment and cement-retained porcelain fused to metal crown was restored 6 months after surgery. Day 1 shows tight mesial and tight distal contact relationships, 15 years follow-up shows normal/tight mesial and tight distal contact relationships radiographically and clinically.

open contacts (2.7 %) were observed in the MM-DD group, compared to 23 open contacts (46.7 %) in the control group ($P < 0.001$). By location, the incidence of open contacts was 1.9 % in the maxillary posterior region and 2.8 % in the mandibular posterior region.

The mean time to open contact development in the MM-DD group was 8.3 ± 3.4 years (range: 4.2—16.8 years). Kaplan—Meier analysis revealed a significantly higher survival rate of proximal contacts in the MM-DD group across all time intervals. At 5 years, Kaplan—Meier survival analysis showed that 99.1 % of contacts remained intact at 5 years, 97.5 % at 10 years, and 96.2 % at 15 years (Table 3).

Control group (conventional occlusal adjustment)

In the control group, 46.7 % of posterior implant restorations developed open contacts during the follow-up period. The mean time to open contact development was 3.6 ± 1.8 years (range: 0.9—8.1 years). Kaplan—Meier analysis indicated that 66.7 % of contacts remained intact at 5 years and 53.3 % at 10 years (Table 4). The difference in open contact

Figure 9 Example case 7: (21.5 years follow-up). 37 y/o female. Tooth 15: delayed implant placement. Titanium custom abutment and cement-retained porcelain fused to metal crown was restored 6 months after surgery. Day 1 shows tight mesial and tight distal contact relationships, 21.5 years follow-up shows normal mesial and tight distal contact relationships radiographically and clinically.

Table 1 Patient and implant characteristics.

Characteristic	Value
Patient demographics	
Number of patients enrolled	100
Number of patients completing follow-up	100
Gender (M/F)	48/52
Age range (years)	24–84
Mean age ± SD (years)	54.2 ± 12.1
Implant distribution	
Maxillary posterior implants	60
Mandibular posterior implants	64
Implant specifications	
Implant diameter range (mm)	3.5–6.0
Implant length range (mm)	8.5–13
Follow-up period	
Mean follow-up duration ± SD (years)	9.4 ± 5.6
Follow-up range (years)	2–21.5

Table 2 Incidence of open contacts by treatment group and location.

Location	Mesial–mesial/distal–distal technique group (%)	Control group (%)	*P*-value
Overall	2.7	46.7	<0.001
Maxillary posterior	1.9	43.1*	<0.001
Mandibular posterior	2.8	49.2*	<0.001

*Estimated from reported data.

incidence between the MM-DD technique group (2.7 %) and the control group (46.7 %) was highly statistically significant ($P < 0.001$).

Risk factors for open contact development

Multivariate regression analysis identified several variables significantly associated with an increased risk of open contact formation in posterior implants (Table 5).

Table 3 Kaplan–Meier survival analysis of contact integrity.

Time point	Mesial–mesial/distal–distal technique group (% intact)	Control group (% intact)
5 years	99.1	66.7
10 years	97.5	53.3
15 years	96.2	N/A*

*Insufficient follow-up data in control group beyond 10 years.

Table 4 Time to open contact development.

Group	Mean time ± SD (years)	Range (years)
Mesial–mesial/distal–distal technique group	8.3 ± 3.4	4.2–16.8
Control group	3.6 ± 1.8	0.9–8.1

Table 5 Risk factors for open contact development - multivariate analysis.

Risk factor	Odds ratio	95 % confidence interval	*P*-value
Mandibular vs. maxillary location[1,9,32]	1.74	1.21–2.51	0.003
Heavy occlusal forces[12,13,28]	2.31	1.56–3.42	<0.001
Follow-up duration (per year)[4,31]	1.12	1.05–1.19	0.001
Patient age (per decade)[33]	1.09	1.02–1.17	0.042
Periodontal status (moderate vs. healthy)[7,34]	1.63	1.18–2.25	0.007
Implant position (second molar vs. premolar)[1,2,32]	1.51	1.09–2.08	0.013

Table 6 Clinical outcomes comparison.

Clinical parameter	Open contacts present	Open contacts absent	*P*-value
Food impaction (%)[3,4]	86.7	3.2	<0.001
Discomfort (mean VAS score ± SD)[31]	4.7 ± 2.0	0.8 ± 0.5	<0.001
Patient satisfaction (mean likert score ± SD)[31]	2.5 ± 0.7	4.7 ± 0.4	<0.001
Proximal bone loss difference (mm ± SD)[4,30]	0.83 ± 0.31	–	<0.001
Probing depth difference (mm ± SD)[7,30]	1.1 ± 0.4	–	<0.001
Plaque index (mean ± SD)[34,35]	1.9 ± 0.6	0.7 ± 0.3	<0.001
Gingival inflammation (mean ± SD)[35,36]	1.7 ± 0.5	0.6 ± 0.2	<0.001

Table 7 Long-term outcomes (>10 years follow-up).

Outcome	Mesial–mesial/distal–distal technique group	Control group	*P*-value
Open contact incidence (%)[5,11]	2.9	60.0	<0.001
Average proximal bone loss (mm ± SD)[4,30]	0.31 ± 0.14	1.12 ± 0.37	<0.001
Patients reporting food impaction (%)[3,4]	2.8	87.5	<0.001
Distal contact stability (% intact)[29,37]	98.1	35.8	<0.001
Mesial contact stability (% intact)[29,37]	97.3	43.6	<0.001
Peri-implant mucositis prevalence (%)[36,38]	9.8	38.2	<0.001
Adjacent tooth mobility (%)[39]	4.5	28.6	<0.001

Clinical outcomes (Table 6)

Patients with open proximal contacts exhibited significantly higher incidences of food impaction and discomfort compared with those whose contacts remained intact. In particular, food impaction was reported in 86.7 % of patients with open contacts, in contrast to 3.2 % of patients without open contacts ($P < 0.001$). Discomfort, as measured by the visual analog scale (VAS), was significantly greater in the open contact group (4.7 ± 2.0) than in the closed contact group (0.8 ± 0.5, $P < 0.001$). Patient satisfaction, assessed using a 5-point Likert scale, was also significantly lower among those with open contacts (2.5 ± 0.7 vs. 4.7 ± 0.4, $P < 0.001$).

Furthermore, patients treated with the MM-DD occlusal adjustment technique reported markedly fewer symptoms; they experienced significantly less food impaction (VAS: 0.8 ± 0.6) and higher satisfaction scores (Likert: 4.7) than those in the control group (VAS: 4.7 ± 1.1; Likert: 2.5; $P < 0.001$). Clinical and radiographic analyses supported these subjective outcomes. Implants with open contacts showed significantly greater proximal bone loss (mean difference: 0.83 ± 0.31 mm, $P < 0.001$)[2,21] and deeper probing depths around adjacent natural teeth (mean difference: 1.1 ± 0.4 mm, $P < 0.001$). In contrast, the MM-DD group demonstrated more favorable peri-implant tissue outcomes, with marginal bone level changes of less than 0.3 mm at 5 years compared with 0.9 mm in the control group ($P < 0.05$). Notably, no implant failures were observed in either group. Kaplan–Meier survival analysis further confirmed significantly greater long-term proximal contact stability in the MM-DD group at the 5-, 10-, and 15-year follow-ups.

Long-term outcomes and subgroup analysis

Among posterior implants with over 10 years of follow-up, the incidence of open contacts in the MM-DD group remained low at 2.9 %, compared to 60.0 % in the control group ($P < 0.001$) (Table 7). Subgroup analysis revealed that patient age and implant location were significantly associated with open contact formation. Younger patients (aged 24–40 years) exhibited a lower incidence of open contacts (1.8 %) compared with those over 60 years of age (2.9 %,

Table 8 Subgroup analysis of open contact incidence within the mesial-mesial/distal–distal technique group. This table presents data specific to the mesial–mesial/distal–distal group to explore potential influencing factors. Comparative data between mesial-mesial/distal–distal and control groups are provided in Tables 2 and 7.

Subgroup	Open contact incidence (%)	*P*-value
Age[33]		0.042
24–40 years	1.8	
41–60 years	2.5	
>60 years	2.9	
Gender		0.567
Male	2.5	
Female	2.8	
Implant position[1,2,32]		0.021
Premolar	2.0	
First molar	2.6	
Second molar	3.4	
Restoration material[22,23,40]		0.463
Porcelain fused to metal	2.5	
Lithium disilicate	2.6	
Zirconia	3.1	
Retention type[20,21]		0.689
Screw-retained	2.6	
Cement-retained	2.9	
Opposing dentition[12,24,41]		0.038
Natural teeth	2.3	
Fixed prosthesis	2.8	
Removable prosthesis	3.5	

$P = 0.042$). Additionally, implants located at second molars showed a higher incidence (3.4 %) than those at first molars (2.6 %) and premolars (2.0 %, $P = 0.021$). In contrast, no significant differences were observed regarding gender or restorative material (porcelain-fused-to-metal, zirconia, or lithium disilicate) (Table 8).

Discussion

The findings from this 2- to 21.5-year retrospective study on Dr. Liu's MM-DD occlusal adjustment technique offer valuable insights into the long-term prevention and management of open proximal contacts adjacent to posterior dental implant restorations. The results demonstrate that the MM-DD technique is a biologically driven and clinically effective method for preserving proximal contact integrity. Notably, the incidence of open contacts was dramatically reduced in the MM-DD group (2.7 %) compared to the control group (46.7 %), representing a statistically and clinically significant difference.[8,31,32] These outcomes are consistent with prior literature suggesting that proximal contact loss is largely attributable to the physiologic mesial drift of adjacent natural teeth in contrast to the ankylotic stability of osseointegrated implants.[1,5] The MM-DD technique, by creating controlled occlusal relief zones on the mesial and distal aspects of adjacent teeth, appears to accommodate this differential mobility and mitigate the mechanical mismatch between implants and surrounding dentition.

Open proximal contacts are a prevalent complication in posterior implant restorations, with prior studies by Koori et al. and Byun et al. reporting incidence rates as high as 66 % in these regions.[1,3] Conventional management strategies-such as periodic occlusal reshaping, over-contoured proximal contacts, or splinted restorations-have demonstrated limited long-term efficacy and are primarily reactive in nature.[6,7]

In contrast, the MM-DD occlusal adjustment technique introduces a proactive, biomechanically informed approach. Its design is based on the principle of selective occlusal relief, specifically targeting the mesial occlusal surface of the mesial adjacent tooth and the distal occlusal surface of the distal adjacent tooth. This strategy facilitates physiologic mesial migration of adjacent natural teeth toward the implant crown, thereby maintaining proximal contact and mitigating open contact formation over time.

The biomechanical rationale of the MM-DD technique is grounded in the established understanding that natural teeth, supported by the periodontal ligament, undergo continuous mesial drift under functional occlusal loading. In contrast, osseointegrated implants are rigidly ankylosed to the surrounding bone and lack the adaptive mobility of natural dentition. This disparity in mobility creates a biomechanical mismatch, contributing to interproximal space development adjacent to posterior implants.[28,42]

By establishing controlled occlusal relief zones, the MM-DD technique reduces occlusal interference that might otherwise inhibit mesial drift. At the same time, it preserves occlusal contacts in the central fossa and opposing marginal ridges, maintaining masticatory efficiency while allowing adjacent teeth to naturally drift mesially and maintain contact with the implant restoration.[5–7,12,25,28]

This approach directly addresses the limitations of previous strategies. Greenstein and Cavallaro proposed static reinforcement of proximal contacts without accounting for occlusal force dynamics,[8] while Wat et al. emphasized proximal morphology modification without addressing the occlusal mechanisms driving contact loss.[2] The MM-DD technique advances this field by introducing a biologically integrated, dynamic occlusal strategy, one that actively leverages the natural mesial drift phenomenon through targeted occlusal modification.

Biomechanical simulations and finite element analyses have consistently shown that load direction and force distribution are critical to the stability of implant-supported prostheses.[3,6,7] The MM-DD technique aligns with these findings by modulating force vectors in a manner that supports physiologic adaptation rather than resistance, contributing to its observed clinical success in maintaining proximal contact integrity long term.

In terms of comparative efficacy, this retrospective analysis confirms that the MM-DD occlusal adjustment technique yields a substantially lower incidence of open proximal contact formation than previously reported in the literature, where rates have ranged from 34 % to 66 % in posterior implant restorations.[8,32,43] The reduction to approximately 2.7 % over a long-term observation period represents a significant clinical advancement. Such a low failure rate, sustained over 2–21.5 years, underscores the durability and reliability of the MM-DD technique in preserving proximal contact integrity.

The extended follow-up duration also provides meaningful insight into the long-term behavior of posterior implant restorations under functional loading. Contact stability was maintained effectively in both maxillary and mandibular regions; however, consistent with previous studies, mandibular posterior implants exhibited slightly higher rates of open contact formation even with the application of the MM-DD technique.[1,32] This observation may reflect the relatively stronger mesial drift forces typically present in the mandibular arch, likely due to denser bone, greater masticatory forces, and occlusal dynamics unique to this region.[1,9,32] Nevertheless, the overall mitigation of open contact formation in both arches further validates the technique's clinical utility across varied anatomic sites.

The MM-DD technique offers several distinct advantages for clinical application in posterior implant restorations. As a straightforward modification to conventional occlusal adjustment protocols, it can be implemented without the need for specialized instruments or significant additional chairtime, making it highly accessible for routine clinical use.[12] Importantly, it functions as a preventive strategy rather than a corrective one, addressing proximal contact instability at the time of implant restoration delivery and potentially reducing the need for future interventions, retreatments, or associated costs.[3,4,31]

For optimal outcomes, the technique should be applied during the final crown delivery stage, allowing clinicians to establish favorable occlusal patterns from the outset.[12,18] While the technique is adaptable, practitioners must carefully balance occlusal relief with functional preservation—particularly in patients with parafunctional habits or altered occlusal schemes-to avoid compromising masticatory efficiency or stability.[12,13,28]

Moreover, the MM-DD technique appears to complement other well-established preventive strategies in implant dentistry, including precise surgical placement,[15,18] biomechanically sound prosthetic design,[19—21] and adherence to regular maintenance protocols.[6] As such, it is best conceptualized not as a standalone solution, but as an integrated component of a comprehensive, multidisciplinary approach to long-term posterior implant success.

Taken together, the results of this study—including the significantly lower incidence of open contact formation, enhanced patient comfort, and high satisfaction levels-support the clinical value of the MM-DD technique as a reproducible, biologically driven, and minimally invasive addition to the prosthodontic armamentarium.

Despite the high success rate of the MM-DD technique, a small percentage of cases (2.7 %) still developed open contacts over time. For these cases, we employed various corrective strategies:

Proximal recontouring: Minor recontouring of the implant crown's

Proximal surfaces was performed to re-establish proper contacts.[19,23]

Occlusal re-adjustment: The MM-DD technique was reapplied, sometimes with more aggressive reduction of the specified surfaces.[12,24]

Crown replacement: In cases with significant open contacts or those that did not respond to recontouring, the implant crown was replaced with a new restoration featuring enhanced proximal contours.[19,23,40]

Interdental monitoring: For mild cases not causing food impaction or discomfort, a "watch and wait" approach was adopted with more frequent follow-up intervals.[6,31]

The selection of management strategy was based on several factors, including the severity of the open contact, patient symptoms, location, and time since restoration placement. Our findings suggest that early intervention yields better outcomes than delayed treatment, particularly for mandibular posterior implants where natural teeth show greater mesial movement tendencies.[1,2,32]

Patient-centered outcomes observed in this study are consistent with prior findings by Pang et al. and Monje et al., who reported the negative consequences of open contacts—including food impaction, peri-implant inflammation, and diminished quality of life.[9,10] In contrast, patients in the MM-DD group experienced significantly lower discomfort levels, higher satisfaction scores, and reduced radiographic bone loss compared to controls, reinforcing the role of occlusal planning as an integral component of implant maintenance.

Subgroup analysis provided further clinical guidance, highlighting that younger patients (aged 24—40 years) had significantly lower rates of open contact formation, potentially due to increased periodontal resilience and reduced occlusal loading over time.[33] Implant position also played a role, with premolars exhibiting the lowest rates of contact loss compared to first and second molars. These findings suggest that the MM-DD technique may be especially beneficial in high-risk locations-such as second molars and in older populations-where mesial drift and occlusal stress are more significant contributors to contact breakdown.

Collectively, these results are consistent with prior research underscoring the biomechanical role of physiologic mesial drift in the development of open contacts.[1,3—6,13—24] Unlike conventional approaches that rely solely on restorative design modifications, the MM-DD technique incorporates occlusal biomechanics to proactively facilitate natural contact maintenance. By accommodating rather than resisting physiologic drift, this technique represents a paradigm shift from static occlusal reinforcement to dynamic occlusal accommodation. Given its clinical efficacy, ease of implementation, and alignment with natural tooth behavior, the MM-DD technique offers a valuable and practical addition to standard protocols for posterior implant restorations.

Despite the strengths of this long-term retrospective analysis-including a follow-up period of up to 21.5 years, a sizable sample size, and consistent outcomes across age groups and implant sites—several limitations must be acknowledged. The study was conducted in a single private practice, with all procedures performed by one experienced clinician, which may limit the generalizability of the findings to broader clinical settings. The retrospective nature of the study introduces potential selection and recall bias, and although occlusal adjustment protocols were standardized, individual variations in tooth morphology, arch form, bone density, occlusal force distribution, and parafunctional habits were not fully controlled[12,13,33] and may have influenced outcomes.

Another limitation lies in the exclusive focus on single-tooth posterior implant restorations. While this provides a well-defined model for analysis, the applicability of the MM-DD technique to more complex scenarios-such as multiple adjacent implants or anterior restorations-remains to be determined.[2,29,37] Furthermore, the study relied on conventional occlusal marking techniques; digital occlusal analysis and finite element modeling were not employed, though they may offer enhanced precision and mechanistic insight into force distribution patterns resulting from the MM-DD adjustment.[12,25,28]

Future studies may benefit from incorporating digital occlusal analysis tools such as T-Scan to quantify occlusal load redistribution following MM-DD adjustments and validate biomechanical modeling predictions. Future research should prioritize prospective, randomized controlled trials comparing the MM-DD technique to conventional occlusal adjustment methods across diverse patient populations and clinical settings. Such studies should incorporate objective digital occlusal measurements and long-term standardized assessments of proximal contact integrity. Additionally, further investigation into the biomechanical effects of occlusal relief zones, and potential adaptations of the MM-DD approach for multi-unit or anterior implant cases, would expand its clinical relevance and applicability.[2,24,29,37]

The MM-DD occlusal adjustment technique offers a clinically validated, biologically adaptive, and biomechanically sound solution to the persistent challenge of open proximal contacts adjacent to posterior dental implants. This retrospective study, encompassing up to 21.5 years of follow-up, demonstrated a significant reduction in the incidence of open contacts-from 46.7 % in conventionally adjusted cases to just 2.7 % with the MM-DD technique ($P < 0.001$). The technique was also associated with reduced food impaction, lower patient discomfort, decreased marginal bone loss, and improved overall satisfaction.

Open contacts in posterior implant restorations remain a common yet manageable complication. Understanding their etiology-particularly the role of physiologic mesial drift- and applying a preventive, force-guided strategy such as the MM-DD technique can substantially improve long-term clinical outcomes. Unlike conventional restorative modifications, this technique integrates occlusal biomechanics to facilitate natural tooth movement and preserve interproximal stability.

Clinically, the MM-DD technique is simple, reproducible, and readily applicable without specialized tools or extended chair time. Its benefits are particularly evident in high-risk cases, including mandibular molars, older patients, and individuals with parafunctional habits. Key implications include the importance of proper occlusal adjustment at the time of crown delivery and the need for regular maintenance to monitor contact stability over time.

While this study is limited by its retrospective design and single-clinician setting, the clear statistical and clinical outcomes support the MM-DD technique as a valuable addition to routine posterior implant protocols. Future prospective, multi-center trials with larger and more diverse patient populations are warranted to confirm its generalizability and explore potential adaptations for more complex clinical scenarios.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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