Open contacts adjacent to dental implant restorations

Etiology, incidence, consequences, and correction

Gary Greenstein, DDS, MS; Joseph Carpentieri, DDS; John Cavallaro, DDS

ABSTRACT

Background. The aim of this investigation was to evaluate the potential causes, clinical significance, and treatment of open contacts between dental implant restorations and adjacent natural teeth.

Types of Studies Reviewed. The authors searched the dental literature for clinical trials in humans that addressed the incidence of open contacts that develop after implant restorations are placed next to teeth.

Results. The authors found 5 studies in which the investigators addressed the incidence of open contacts after implant restorations are inserted next to teeth. Results from these studies indicated that an interproximal gap developed 34% to 66% of the time after an implant restoration was inserted next to a natural tooth. This event occurred as early as 3 months after prosthetic rehabilitation, usually on the mesial aspect of a restoration.

Conclusions. The occurrence of an interproximal separation next to an implant restoration was greater than anticipated. It appears that force vectors cause tooth movement and an implant functions like an ankylosed tooth.

Practical Implications. Clinicians should inform patients of the potential to develop interproximal gaps adjacent to implant restorations, which may require repair or replacement of implant crowns or rehabilitation of adjacent teeth. Furthermore, steps should be taken to check the continuity of the arch periodically. If the clinician detects an open contact, it is prudent to monitor for signs or symptoms of pathosis so that prosthetic repair of the gap can be initiated, if needed. These problems could add to treatment costs and decrease overall patient satisfaction related to implant treatment.

Key Words. Implants; restorative dentistry; operative.
JADA 2016:147(1):28-34
http://dx.doi.org/10.1016/j.adaj.2015.06.011

Development of an open contact between a restored dental implant and a contiguous tooth, where initially there was a firm proximal contact, occurs more often than expected (Figures 1 and 2).[1-5] An interproximal gap can result in a food trap, caries, and periodontal issues and precipitate the need for prosthetic repairs.[1-5] These untoward consequences are disconcerting for the patient and clinician.

Occlusal forces are transmitted via contact areas, and mesial migration compensates for proximal tooth wear, thereby maintaining intra-arch continuity.[1-5] Failure to maintain a firm contact after an implant restoration is placed often happens on the mesial aspect of the crown, but it can occur distally (Table).[2,4] An open contact in an adult dentition adjacent to an implant restoration is usually due to physiological mesial drifting of teeth while the implant remains stationary.[1,2,4] In this article, we address the etiology, incidence, consequences, and repair of open contacts between dental implant restorations and adjacent natural teeth.

ANTERIOR COMPONENT OF FORCE

There are 4 primary forces that influence the dentition's arrangement: tongue and lips, personal behavior (for example, habits) or orthodontic appliances, periodontal membrane, and occlusal forces.[6] The last factor provides the major force vector associated with physiological tooth migration.[7-9]

The main muscles of mastication involved with jaw closure are the medial pterygoid, masseter, superior division of the lateral pterygoid, and temporalis muscles.[10]

On mandibular closure, forces created by these muscles are directed in different directions by the teeth's inclined planes. The forward vector is referred to as the *anterior component of force* (ACF), and it drives teeth mesially.[7-9] There also is a force that pushes teeth distally, but the mesial vector is 5 times stronger than the posterior force.[11] The strength of the ACF increases proportionally to the magnitude of the bite force.[8,12]

In 1923, Stallard[13] suggested that the arc of mandibular closure caused an ACF on mandibular posterior teeth that was transmitted via interproximal contacts between the teeth and that this vector drove teeth mesially as the contact points wore because of friction. Subsequently, Conroy[12] subjected all the teeth individually in a mandibular quadrant to a controlled force (a custom bite force transducer was fabricated and connected to a strain indicator) and assessed the magnitude of the ACF. He noted that the ACF was transmitted via the interproximal contacts and that its strength decreased with increased distance from the posterior teeth. In addition, he also confirmed that there was a posterior component of force.

PROXIMAL CONTACTS

Arrangement of interproximal interfaces among human teeth. The size and location of contact areas vary with age, tooth position, biting force, and crowding of teeth.[14] The contour of the contact interfaces is predominantly oval and usually found toward the buccal aspect of interproximal areas. In the incisal region, their outline is more vertical than horizontal, and in the posterior sextants of the arch, the shape of an interproximal contact is more horizontal than vertical.[15] Sarig and colleagues[14] reported that normally the interproximal interface with or without wear decreases in size from molars to incisors. They suggested that larger contact areas are needed in the posterior teeth to resist attrition where there is increased biting force.[14]

Over time, the morphology of contact areas changes because of attrition and physiological drifting. The oval contacts often become kidney shaped. This change is associated with flattening of the contact area, which creates room for the dentition to move mesially. To reduce this change, Sarig and colleagues[14] suggested enlarging the interproximal interfaces of restorations to increase tooth position stability.

From another perspective, the contact area between a tooth and an implant restoration needs to be modified after an extraction. Tooth removal results in reduction of the interdental tissue volume because of shrinkage of the papilla and bone loss between the tooth and a future implant restoration. To compensate for a larger embrasure or concave shape of an adjacent tooth, the clinician often needs to use a longer, broader, wider contact in an occlusogingival dimension.

Figure 1. Radiograph showing delivery of an implant-supported restoration at site no. 30 on November 29, 2010. A broad, wide contact was confirmed clinically with floss.

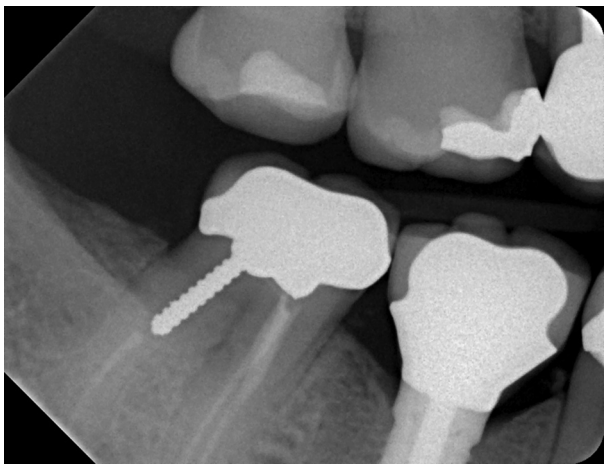

Figure 2. Radiograph showing open contact that developed approximately 1 year after restoration insertion (November 2, 2011) on the mesial aspect of the implant restoration at site no. 30. No interdental pathosis was present.

Reasons for premature loss of contact between teeth. Intact contact areas prevent tooth migration, allow dissipation of ACF, and avoid food impaction. Premature loss of interproximal contacts can occur because of a variety of factors: caries, early loss of a tooth, inauspicious sequence of eruption, ankylosed teeth, congenital issues, and trauma.[14] Loss or alteration of contact areas can result in interproximal black triangles, food impaction, periodontal problems (such as loss of clinical attachment, gingival inflammation, or reduction of interproximal bone), and misalignment of teeth.[14]

ABBREVIATION KEY. ACF: Anterior component of force.

TABLE

Percentage of restored dental implants manifesting open proximal contact areas adjacent to natural teeth.

STUDY	TOTAL PERCENTAGE OF OPEN CONTACT AREAS	NO. OF PATIENTS MONITORED	TOTAL NO. OF CONTACT AREAS	PERCENTAGE OF OPEN CONTACTS ON THE MESIAL ASPECT	PERCENTAGE OF OPEN CONTACTS ON THE DISTAL ASPECT	DEVICE*	TIME
Wei and Colleagues,[1] 2008	58 (32/55)	28	55	58 (32/55)	†	50-μm‡ strip	Up to 2.2 y
Koori and Colleagues,[2] 2010	43 (80/186)	105	186	52 (73/141)	16 (7/45)	50-μm strip	Range, 1 to 123 mo
Wat and Colleagues,[3] 2011	66 (2/3)	1	3	67 (2/3)	Not assessed	Dental floss	2 y
Byun and Colleagues,[4] 2015	34 open 20 loose§ (65/191)	94	191	38 (51/134)	25 (14/57)	Dental floss	Mean, 57 mo (range, 3-156 mo)
Wong and Colleagues,[5] 2015	65 (43/66)	45	66	65 (43/66)	Not assessed	38-μm Toffelmire matrix bands	Mean, 3.9 y (range, 0.5-12 y)

* Different devices were used to assess for the presence of open contacts.
† The authors did not clearly state whether open proximal contacts occurred mesially or distally, so we interpreted the data to indicate that it occurred mesially.
‡ μm: Micrometer.
§ Floss could pass through, but there was a weaker contact than originally determined. These data were from part of the group listed: 94 patients, 191 contacts.

Craniofacial growth: a factor for loss of interproximal contact between teeth. Besides the ACF, adult craniofacial growth can alter tooth positions.[16,17] Historically, Odman and colleagues[18] demonstrated that dental implants function like ankylosed teeth and do not move with additional jaw growth. Thus, implants usually are not inserted in patients who are still growing. With respect to adults, Daftary and colleagues[16] reported that uncommonly there is craniofacial growth in some people beyond adulthood. This growth can result in occlusal alterations. Subtle facial growth may occur mesially, buccally, and vertically.[19] Others also have discussed how facial growth after adulthood can affect the position of teeth.[17,20-22]

RESULTS AND DISCUSSION OF LITERATURE SEARCH

We searched the dental literature for human studies in which the investigators addressed the incidence of open contacts that develop after implant restorations are inserted next to natural teeth. In this review, we included all detected clinical trials in which the investigators described how they assessed the size of open contacts and defined the length of the monitoring period. We found 5 investigations. Investigators in 1 study evaluated only 3 contact points in 1 patient; the other investigations had 28 to 105 patients (Table).[1-5] We conducted the following searches on PubMed: proximal contact loss adjacent to implant prostheses (2 of 6 articles included), loss of interproximal contact adjacent to implant prostheses (2 of 3 articles included), migration of teeth because of occlusal forces (1 of 36 articles included), and implant prostheses and adjacent tooth migration (2 of 12 articles included).

INCIDENCE OF OPEN CONTACTS BETWEEN DENTAL IMPLANTS AND NATURAL TEETH

The table[1-5] lists how often we found reports of open contacts adjacent to restored implant restorations in different studies. Byun and colleagues[4] differentiated between development of open contacts (floss passes between teeth unimpeded) and creation of loose contacts (floss encounters weak resistance). They reported open contacts at 38% of assessed sites and loose contacts at 20% of the proximal surfaces monitored over a mean 57-month period (range, 3-156 months). They found the first open contact 8 months after a restoration was inserted. Koori and colleagues[2] recorded an increased incidence of interproximal gaps (43% of study population) over 1 to 123 months. Wei and colleagues[1] documented a larger occurrence of open proximal contacts (58%), and they occurred within a short period (up to 2.2 years). They noted the first open contact 3 months after crown insertion. In a multipatient study, Wong and colleagues[5] reported the largest incidence of open contacts (65%) during a monitoring period of 0.5 to 12 years. They also found that the amount of open contacts was similar among prostheses that were screw or cement retained.

With increased time, the size of the space between teeth and an implant restoration may enlarge,[3,5] and the number of open contacts increased with the passage of time.[1,2,4,5]

The prevalence of interproximal open contacts varied between studies.[1-5] Factors that could contribute to different findings are patient age, different study populations, types of adjacent restorations, occlusal forces,

opposing dentition, monitoring time, and the methods used to assess the integrity of the interproximal areas.

Mesial versus distal development of open contacts. Byun and colleagues[4] reported that mesial contact areas of implant restorations next to a natural tooth manifested a gap more often than did distal aspects. They found 38% (51 of 134) of the mesial contacts opened versus 25% (14 of 57) of the distal contacts (Table).[1-5] This finding was less than that observed by Koori and colleagues,[2] who reported 52% (73 of 141) of the mesial and 16% (7 of 45) of the distal contacts were open by the end of the assessment period (Table).[1-5]

Koori and colleagues[2] also indicated that loss of contact occurred more frequently in the mandible than the maxilla. The reason for this finding is unclear. In addition, they demonstrated that more migration of teeth was seen when the opposing dentition was composed of natural teeth rather than a partial or full denture because natural teeth generate greater occlusal forces.[2] However, the investigators in the studies we assessed used different methodologies to evaluate the tightness of contact areas (Table).[1-5]

MAGNITUDE OF ALTERED TOOTH POSITION BECAUSE OF MESIAL MIGRATION OF TEETH

Investigators reported different amounts of actual tooth migration, which could be affected by the duration of the assessment time, bite force, and so on. By age 40 years, the ACF results in 0.5 centimeters (5 millimeters) of mesial migration of teeth.[23] These alterations occurred gradually, with periods of activity and remission. In addition, as teeth moved mesially, the alveolar bone was altered. Bone resorption occurred on the mesial aspect because of pressure, and bundle bone formed on the distal surfaces of teeth because of tension.[23] However, among Swedish adults, investigators found a smaller proximal wear rate (1 mm per arch over 9 years).[24] Carter and McNamara[25] noted a slightly larger wear rate in people aged 17 to 48 years. Among males, the mandibular arch perimeter was reduced 2.4 mm, and in the maxilla it decreased 1.86 mm. Females demonstrated an alteration of 1.76 mm in the mandible and 2.06 mm in the maxilla. Carter and McNamara[25] concluded that changes over years usually were not clinically significant because the adjustment of a full-cusp Angle Class II molar relationship is approximately 5 mm.

Other factors also can influence mesial migration of teeth. Wei and colleagues[1] suggested that high occlusal forces on teeth adjacent to an implant restoration could affect the degree of mesial migration. In addition, Koori and colleagues[2] stated that age, condition of the opposing dentition, vitality of adjacent teeth, and splinting of the adjacent teeth may affect the rate of proximal contact loss of a fixed dental prosthesis adjacent to an implant restoration.

ADVERSE CONSEQUENCES CAUSED BY LOSS OF PROXIMAL CONTACT

Open contacts can have negative effects on the dentition: food impaction, caries, migration of teeth, periodontal issues, and additional prosthetic repairs. Several authors stated that subsequent to developing open contacts, patients experienced trapping food.[2,4,5] This trapped food can result in an increased caries rate (Figures 3 and 4).[26] With respect to developing periodontal issues, Byun and colleagues[4] reported no increased incidence of inflammatory peri-implant problems associated with open contacts, whereas Koori and colleagues[2] described a greater amount of clinical attachment loss and deeper probing depths. Others noted adverse affects with respect to periodontal issues when there were open contacts between teeth.[27,28] Different findings concerning periodontal health or caries could be attributed to the level of personal and professional maintenance that was performed and the duration that sites were monitored. Detection of an open contact area between an implant restoration and an adjacent tooth may not lead to negative consequences. Therefore, a clinician should consider the risk-benefit ratio of only monitoring such sites. It may be prudent to eliminate an open contact area to preclude potential problems, such as root caries that can result in tooth loss. However, some patients or clinicians may elect to monitor these situations. In these circumstances, patient compliance with respect to being assessed periodically is important. If a decision is made to close an open contact, the clinician must choose to modify or replace the implant crown or restore the adjacent tooth.

CORRECTION OF ISSUES CREATED BY MESIAL MIGRATION OF TEETH

The average movement of molars during mastication in the horizontal plane is 56 to 75 micrometers and in the vertical plane is 28 μm.[29] In contrast, dental implants demonstrated 5 μm in the vertical plane and 12 to 66 μm in the horizontal plane.[29] Mesial drifting is not found with respect to dental implants,[30,31] which makes them analogous to ankylosed teeth. However, it is hypothetically possible that an open contact could develop between implants because of facial growth.

After 2 years, Wat and colleagues[3] noted 0.5-mm gaps had developed between some restored implants (mesial aspect) and adjacent teeth. They removed the affected prostheses and made a new working impression. They added porcelain to the mesial aspect of the dental implants to reestablish proximal contacts. In this regard, there are 2 major issues that require consideration concerning implant crown fabrication: selecting a screw- versus a cement-retained restoration and choice of the restorative material. Selection of a screw- or a cement-retained restoration should provide retrievability to facilitate repair of an open contact. Thus, it would be

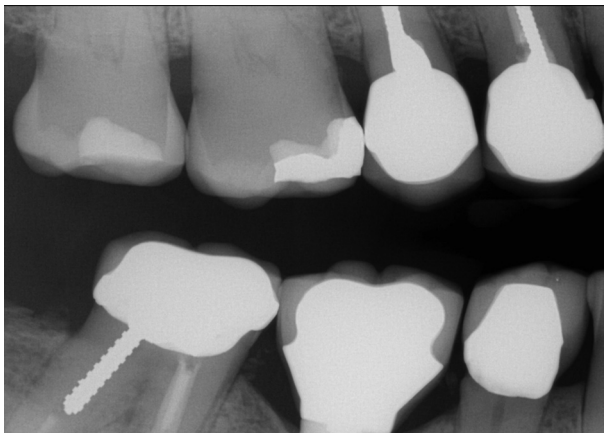

Figure 3. Radiograph showing open contact still present at tooth no. 30 mesial (November 4, 2014), but now there is extensive caries on distal aspect of tooth no. 29, which precipitated the need for a full-coverage restoration on tooth no. 29.

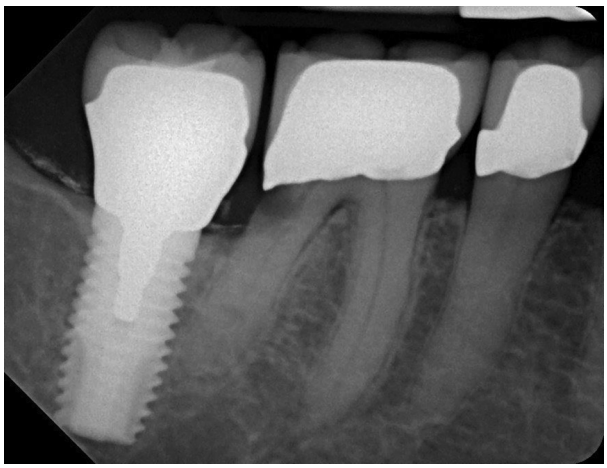

Figure 4. Radiograph illustrating an open contact on the mesial of the implant at site no. 31. Subsequently, caries developed on the distal of tooth no. 30 due to food impaction, and tooth no. 30 needed to be replaced with an implant.

beneficial if cement-retained crowns were inserted with a temporary luting agent. With respect to the restorative format, it will be based on several factors: the clinician's preference, 3-dimensional location of the implant (position, depth, and angulation), and restorative space measured from the implant platform to the opposing arch. Minimally, approximately 5 mm of vertical space is needed for a screw-retained crown and approximately 7 mm for a cement-retained restoration.[32,33] When screw-retained restorations are used, implants should be placed as parallel as possible to the adjacent surfaces because screw-retained prostheses need a line of draw (that is, path of insertion) that allows crowns to be fabricated with contacts of proper shape and size.[32,33]

With respect to selecting a restorative material to fabricate the implant crown, there are several options: porcelain fused to metal or porcelain fused to zirconia with feldspathic ceramic, lithium disilicate glass ceramic (used with computer-aided design and computer-aided manufacturing or press techniques), or full zirconia restorations.[34-36] The choice of the material is an important clinical decision because of differences in each material (such as esthetics, fracture resistance, and cost) and their ability to be modified. When implant restorations are removed, ceramics can be reapplied to restore the contact area for both the porcelain-fused-to-metal and lithium disilicate crowns. Similarly, zirconia monolithic (full-contour zirconia) or bilaminar crowns (zirconia copings layered with feldspathic porcelain) can undergo additive correction as long as they can be retrieved from the mouth. Ultimately, the decision to modify or replace an existing restoration to close an open space needs to be made with respect to the following factors: ease of retrievability, the choice of materials, finances, esthetics, and the size and predictability of the potential modification, as well as the expertise of the laboratory technician.

OCCLUSAL EQUILIBRATION TO MODIFY DISTAL OPEN CONTACTS

Kurthy[37] advocated occlusal adjustment to reverse the development of open contacts between natural teeth and implants if the open contact develops distal to an implant. However, his technique cannot be used universally because most open contacts develop on the mesial aspect of an implant and his technique applies to specific situations in which the implant would have to be next to the last tooth in the arch.

RETAINERS OR NIGHT GUARDS

Occlusal forces can have a detrimental effect on natural teeth and restorations on teeth or implants, particularly in patients with bruxism. An easy technique to preserve tooth patterns and porcelain and to relieve masticatory stress is to fabricate a retainer or night guard.[38,39] Conceptually, use of a retainer should decrease attrition of tooth contacts and reduce open contacts. However, this outcome has not been documented in the literature.

CRITIQUE AND OPINION

The investigations in which the authors assessed the incidence of open contacts were observational studies.[1-5] They were not experimental or controlled studies, and the authors did not investigate any type of therapy that may improve outcomes.[40] The investigators assessed particular populations of patients over time; therefore, the studies are considered longitudinal cohort investigations.

BOX

Suggested guidelines for management of open contacts adjacent to an implant restoration.

- The possibility of future open contacts should be communicated to patients before treatment, and this information should be included in a medicolegal consent form.
- Retrievability of implant restorations is strongly recommended because loss of interproximal contact is fairly common.
- Before impression procedures for implant restorations, modify both adjacent contacts with minor recontouring so they are flatter in profile and rounded, with minor undercuts and rough edges removed.
- If there is an open contact with no food impaction, provide no treatment and carefully monitor patient compliance.
- If there is an open contact with food impaction without pathosis, the first choice is modification of the implant restoration; the second choice is restoring the adjacent tooth.
- If there is an open contact with food impaction and caries, modify the adjacent tooth with a conservative restoration or a new full-coverage restoration to address the caries. If there is a periodontal or peri-implant problem, address it.
- Eliminate open contact areas to preclude potential problems, especially in patients with high caries rates or history of periodontitis.
- For maintenance and monitoring, use a peri-implant maintenance protocol (3 to 6 months), observe contacts surrounding implants, and reexamine occlusion in the area of the implant restoration.

Prospective observational studies are conducted to collect descriptive information, such as the incidence of open contacts adjacent to dental implants, and to assess associations with respect to causes of a problem. However, confounding variables exist that limit data interpretation. For instance, in all 5 articles in which the authors addressed the incidence of open contacts,[1-5] other quadrants without implants were not used as control groups; therefore, we do not precisely know whether the incidence of open contacts was statistically significantly greater adjacent to implants than when an implant was not placed. This information would facilitate calculation of the absolute and relative risks of developing an open contact with or without implant placement.

The available data indicate a high incidence of open contacts developing subsequent to insertion of implant restorations adjacent to natural teeth. We have noticed this phenomenon but not at the level of occurrence reported in the table.[1-5] As previously listed, possible explanations for dissimilar findings include unlike study populations, disparate methods of assessing contact tightness, duration of monitoring, different opposing dentitions, biting force, prosthesis design, and buccolingual and occlusogingival dimensions of restoration contact areas. Another factor that could account for discrepancies between study populations is the use of different statistical methods. For example, Byun and colleagues[4] used a generalized estimating equation so that multiple sites could be considered from each patient, whereas others did not address this issue.[1-3,5] It appears that they had multiple sites per patient, but they did not account for a person's individual biological makeup.

Despite our critical examination of the methods and material in the addressed studies, it was not possible to identify precisely why the reported frequency of open contacts[1-5] seemed greater than that in our experiences. Contrastingly, it could mean that we might need to quantify the occurrence of open contacts in our private practices to validate or refute these findings. Also, some of the open contacts recorded over time in the reviewed studies may have been present at the time of prosthesis placement. Regardless of the precise incidence of open contacts, these phenomena deserve additional attention from clinicians.

One additional point of information: the question could be asked as to why a tooth mesial to an implant would move anteriorly, because forces are not being transmitted via a contact point on the distal of the tooth where the implant remains motionless. The answer is that continued movement mesially is due to occlusal vector forces provided by the opposing dentition.

CONCLUSIONS

Development of open contacts generally does not occur between natural teeth because of physiological drift,[14] so the finding that this occurs among patients with implants indicates that there is something more than mesial migration occurring. The probable reason that an open contact occurs is that an implant is "ankylosed" and cannot shift like the other teeth.

The precise etiology of an open contact adjacent to an implant is unclear; it may be due to the ACF, or it may be multifactorial and related to changes in occlusion.[1,2] In this regard, physiological migration does not explain the occurrence of open distal contacts adjacent to implant restorations.

The data indicate that open contacts occur more often than expected between restored implants and natural teeth, which creates a dilemma for restorative practitioners. Accordingly, clinicians should monitor patients to determine whether they are developing open contacts. If this occurs, they may require modification of existing implant restorations or adjacent teeth. Implant restorations should be retrievable so that contact points can be restored as needed.[3] Furthermore, retainers may help reduce the incidence of open contacts between restored implants and teeth; however, as indicated, there are no data in the literature addressing this specific issue. Koori

and colleagues[2] advised that clinicians should include in their informed consent statements comments advising patients that development of open contacts adjacent to implant restoration is an unpredictable event and that its occurrence may dictate the need for prosthetic repair of the contact area. As a final thought, there are no precise guidelines with respect to the management of an open contact associated with implant restorations; however, closing the gap is an approach that reduces potential complications. The box lists suggested guidelines for management of open contacts between an implant and an adjacent tooth. ■

Dr. Greenstein is a clinical professor, College of Dental Medicine, Columbia University, New York, NY, and maintains a private practice in surgical implantology and periodontics in Freehold, NJ. Address correspondence to Dr. Greenstein at 900 W. Main St., Freehold, NJ 07728, e-mail ggperio@aol.com.

Dr. Carpentieri is a clinical assistant professor, College of Dental Medicine, Columbia University, New York, NY, and maintains a private practice in surgical implantology and prosthodontics in White Plains, NY.

Dr. Cavallaro is a clinical professor, College of Dental Medicine, Columbia University, New York, NY, and maintains a private practice in surgical implantology and prosthodontics in Brooklyn, NY.

Disclosure. Dr. Carpentieri is a consultant and speaker for Zimmer Biomet. Dr. Cavallaro is a consultant and speaker for Implant Direct International. Dr. Greenstein did not report any disclosures.

1. Wei H, Tomotake Y, Nagao K, Ichikawa T. Implant prostheses and adjacent tooth migration: preliminary retrospective survey using 3-dimensional occlusal analysis. *Int J Prosthodont*. 2008;21(4):302-304.

2. Koori H, Morimoto K, Tsukiyama Y, Koyano K. Statistical analysis of the diachronic loss of interproximal contact between fixed implant prostheses and adjacent teeth. *Int J Prosthodont*. 2010;23(6):535-540.

3. Wat PY, Wong AT, Leung KC, Pow EH. Proximal contact loss between implant supported prostheses and adjacent natural teeth: a clinical report. *J Prosthet Dent*. 2011;105(1):1-4.

4. Byun SJ, Heo SM, Ahn SG, Chang M. Analysis of proximal contact loss between implant-supported fixed dental prostheses and adjacent teeth in relation to influential factors and effects: a cross-sectional study. *Clin Oral Implants Res*. 2015;26(6):709-714.

5. Wong AT, Wat PY, Pow EH, Leung KC. Proximal contact loss between implant-supported prostheses and adjacent natural teeth: a retrospective study. *Clin Oral Implants Res*. 2015;26(4):e68-e71.

6. Proffit WR. Equilibrium theory revisited: factors influencing position of the teeth. *Angle Orthod*. 1978;48(3):175-186.

7. Southard TE, Behrents RG, Tolley EA. The anterior component of occlusal force. Part 2. Relationship with dental malalignment. *Am J Orthod Dentofacial Orthop*. 1990;97(1):41-44.

8. Southard TE, Southard KA, Stiles RN. Factors influencing the anterior component of occlusal force. *J Biomech*. 1990;23(12):1199-1207.

9. Southard TE, Behrents RG, Tolley EA. The anterior component of occlusal force. Part 1. Measurement and distribution. *Am J Orthod Dentofacial Orthop*. 1989;96(6):493-500.

10. Carranza F, Solberg W. Masticatory function. In: Carranza F, ed. *Glickman's Periodontology*. 6th ed. Philadelphia, PA: WB Saunders; 1984:70.

11. Vardimon AD, Beckmann S, Shpack N, et al. Posterior and anterior components of force during bite loading. *J Biomech*. 2007;40(4):820-827.

12. Conroy JJ. *An Investigation of the Posterior Component of Occlusal Force* [master's thesis]. Iowa City, IA: University of Iowa; 1994:1-115.

13. Stallard H. The anterior component of the force of mastication and its significance to the dental apparatus. *Dent Cosmos*. 1923;65(5):457-474.

14. Sarig R, Lianopoulos NV, Hershkovitz I, Vardimon AD. The arrangement of the interproximal interfaces in the human permanent dentition. *Clin Oral Investig*. 2013;17(3):731-738.

15. Stappert CF, Tarnow DP, Tan JH, Chu SJ. Proximal contact areas of the maxillary anterior dentition. *Int J Periodontics Restorative Dent*. 2010;30(5):471-477.

16. Daftary F, Mahallati R, Bahat O, Sullivan RM. Lifelong craniofacial growth and the implications for osseointegrated implants. *Int J Oral Maxillofac Implants*. 2013;28(1):163-169.

17. Heij DG, Opdebeeck H, van Steenberghe D, et al. Facial development, continuous tooth eruption, and mesial drift as compromising factors for implant placement. *Int J Oral Maxillofac Implants*. 2006;21(6):867-878.

18. Odman J, Gröndahl K, Lekholm U, Thilander B. The effect of osseointegrated implants on the dento-alveolar development: a clinical and radiographic study in growing pigs. *Eur J Orthod*. 1991;13(4):279-286.

19. Brash JC. The growth of the alveolar bone and its relation to the movements of the teeth, including eruption. *Int J Orthod*. 1928;14(5):196-223.

20. Bahat O, Chu S, Daftary F, Mahallati R, Tarnow D. Interactive session: managing the unaesthetic implant. Paper presented at: 100th Annual Meeting of the American Academy of Periodontology. September 19-22, 2014; San Francisco, CA.

21. Jemt T, Ahlberg G, Henriksson K, Bondevik O. Tooth movements adjacent to single-implant restorations after more than 15 years of follow-up. *Int J Prosthodont*. 2007;20(6):626-632.

22. Oesterle LJ, Cronin RJ Jr. Adult growth, aging, and the single-tooth implant. *Int J Oral Maxillofac Implants*. 2000;15(2):252-260.

23. Carranza F, Ubios AM. The tooth supporting structures. In: Carranza F, Newman M, eds. *Clinical Periodontology*. 8th ed. Philadelphia, PA: WB Saunders; 1996:538.

24. Lammie GA, Posselt U. Progressive changes in the dentition of adults. *J Periodontol*. 1965;36(6):443-454.

25. Carter GA, McNamara JA Jr. Longitudinal dental arch changes in adults. *Am J Orthod Dentofacial Orthop*. 1981;114(1):88-99.

26. Allison PJ, Schwartz S. Interproximal contact points and proximal caries in posterior primary teeth. *Pediatr Dent*. 2003;25(4):334-340.

27. Hancock EB, Mayo CV, Schwab RR, Wirthlin MR. Influence of interdental contacts on periodontal status. *J Periodontol*. 1980;51(8):445-449.

28. Jernberg GR, Bakdash MB, Keenan KM. Relationship between proximal tooth open contacts and periodontal disease. *J Periodontol*. 1983;54(9):529-533.

29. Sekine H, Komiyama Y, Hotta H, Yoshida K. Mobility characteristics and tactile sensitivity of osseointegrated fixture-supporting systems. In: van Steenberghe D, ed. *Tissue Integration in Oral Maxillofacial Reconstruction*. Amsterdam, Netherlands: Excerpta Medica; 1986:326-332.

30. Thilander B, Odman J, Gröndahl K, Lekholm U. Aspects on osseointegrated implants inserted in growing jaws: a biometric and radiographic study in the young pig. *Eur J Orthod*. 1992;14(2):99-109.

31. Richter EJ. Basic biomechanics of dental implants in prosthetic dentistry. *J Prosthet Dent*. 1989;61(5):602-609.

32. Sailer I, Mühlemann S, Zwahlen M, et al. Cemented and screw-retained implant reconstructions: a systematic review of the survival and complication rates. *Clin Oral Implants Res*. 2012;23(suppl 6):163-201.

33. Lee A, Okayasu K, Wang HL. Screw- versus cement-retained implant restorations: current concepts. *Implant Dent*. 2010;19(1):8-15.

34. Carpentieri JR, Lazzara RJ. A simplified impression protocol for fabrication of anatomical, cement-retained CAD/CAM abutments. *Int J Periodontics Restorative Dent*. 2014;34(suppl 3):s19-s25.

35. Martinez-Rus, Ferreiroa A, Ozcan M, et al. Fracture resistance of crowns cemented on titanium and zirconia abutments: a comparison of monolithic vs manual veneered all-ceramic systems. *Int J Oral Maxillofac Implants*. 2012;27(6):1448-1455.

36. Tysowsky GW. The science behind lithium disilicate: a metal-free alternative. *Dent Today*. 2009;28(3):112-113.

37. Kurthy R. Walking forward: closing unwanted posterior open interproximal contacts. *Dent Today*. 2002;21(9):82-88.

38. Capp NJ. Occlusion and splint therapy. *Br Dent J*. 1999;186(5):217-222.

39. Cowie RR. The clinical use of night guards: occlusal objectives. *Dent Today*. 2004;23(9):112,114-115.

40. Jepsen P, Johnsen SP, Gillman MW, Sørensen HT. Interpretation of observational studies. *Heart*. 2004;90(8):956-960.