The overarching objective of contemporary implant-supported prosthetic rehabilitation is long-term clinical success with minimal complications. Implant complications can be classified as either biologic or biomechanical (ie, prosthetic) in nature. Among these, some of the most frequent and challenging to manage include peri-implant mucositis and peri-implantitis.1

The mean prevalence of peri-implantitis has been estimated to be 45% at the patient level and 25% at the tooth level.2 Commonly, peri-implantitis can lead to peri-implant soft and hard tissue deficiencies and ultimately implant failure.3

The 2017 World Workshop stated that there is robust evidence pointing toward a positive relationship between peri-implantitis and a previous history of periodontitis, poor plaque control, and a lack of regular maintenance visits.4 Overall, the risk factors/indicators with the strongest level of evidence are those pointing toward a biofilm-based etiology for peri-implantitis. Biofilm accumulation and the ability to access dental implants and their restorations for microbial decontamination are directly related to prosthetic design and restorative characteristics. It is a common observation that peri-implant bone remodeling generally begins after delivery of the prosthesis or healing abutment and seldom occurs before this point. Interestingly, up to date, no literature has summarized the current state of the evidence regarding the prosthetic-biologic connection in the context of peri-implant disease pathogenesis. Hence, the aim of this article was to discuss key prosthetic factors that may have an influence on peri-implant bone loss (disease) susceptibility following the chronologic order of treatment, starting from treatment planning considerations all the way up to occlusion.

The Prosthetic–Biologic Connection and Its Influence on Peri-implant Health: An Overview of the Current Evidence

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Prosthetic design is a critical step in implant treatment planning that must synchronize with implant positioning to promote a state of peri-implant health. Improperly designed prostheses may not only hinder patient (or professional) hygiene measures but also impact the ability of clinicians to examine the peri-implant supporting tissues for diagnostic purposes. The purpose of this review was to discuss the current state of the evidence surrounding prosthetic factors associated with peri-implant diseases. Following the chronologic order of implant treatment, key prosthetic variables were discussed in relation to peri-implant disease pathogenesis. Specific concepts including the impact of implant spatial positioning, abutment height, residual cement, and implant splinting were found to be associated with peri-implant disease pathogenesis. Excessive occlusal forces were found to play a role in susceptibility to prosthetic complications with limited evidence to suggest a role in peri-implant disease progression. An intimate prosthetic-biologic connection exists, which must be respected to promote an environment for long-term peri-implant stability and health. Int J Oral Maxillofac Implants 2022;37:690–699. doi: 10.11607/jomi.9523

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RELATIONSHIP BETWEEN IMPLANT POSITIONING AND ACCESS FOR MONITORING AND HYGIENE

Treatment planning philosophies regarding implant positioning have evolved significantly over time, with the weight shifting from placement based on bone availability toward prosthetically driven implant therapy.5 Biologically driven implant therapy was also described.6 Ultimately, the ideal implant position must facilitate fabrication of a functional, esthetic, and cleanable prosthesis. In addition, the three-dimensional implant position and the definitive crown contours are crucial factors
contributing to the maintenance of peri-implant tissue health.

Effect of Buccolingual Implant Position on Peri-implant Health

Buccolingual positioning may directly influence prosthetic design and peri-implant tissue responses. “Too buccal” placement can predispose toward increased peri-implant bone remodeling as well as a higher susceptibility to development of hard and soft tissue deficiencies and esthetic concerns.7 Approximately 2 mm of buccal bone relative to the implant platform is recommended to preclude mucosal recession.8 On the other hand, the often recommended “too lingual” placement may result in an overcontoured restoration facilitating food debris accumulation and hindering access for hygiene and peri-implant probing (Fig 1).9,10

Effect of Vertical Implant Position on Peri-implant Health

In regard to how vertical positioning impacts prosthetic design, “too shallow” implant placement does not allow establishment of adequate peri-implant supracrestal tissue height, frequently resulting in overcontoured restorations (due to a lack of apicocoronal distance between the implant platform and the gingival margin), implant thread exposure, and esthetic concerns. Conversely, if the implant is placed slightly deeper, the restorative dentist has more vertical height to develop a prosthetic profile with a more acute emergence angle (Fig 2a). More acute angles generally facilitate access for hygiene and maintenance.11 On the other hand, deeper implant placement may also lead to a higher propensity for deeper probing depths and may potentially create a niche for pathogenic bacterial accumulation.12,13 A recent systematic review demonstrated that subcrestal implant positioning does not create significant differences in marginal bone loss (MBL) as long as the implants are not placed too deep (> 3 mm subcrestally).14

Effect of Mesiodistal Implant Position on Peri-Implant Health

In respect to horizontal positioning, off-center placement especially in the posterior area affects the restorative emergence profile and has a significant influence on access for hygiene.15 A recent in vitro study advocated for a modified prosthetic design for cases where the horizontal implant position is offset in the mesiodistal dimension to facilitate biofilm removal.16 At posterior sites, this alternative design consists of a slim premolar-like crown in conjunction with a cantilevered pontic. This may facilitate access for oral hygiene through interproximal embrasures (Fig 2b). Off-center implant positioning may be considered in cases where the mesiodistal restorative space limits placement of two adjacent implant-supported crowns but is too large for a single conventional restoration. Further clinical trials should assess the validity of this approach.

Effect of Implant Diameter on Restoration Dimensions

Clinicians are encouraged to match the implant platform with the desired restorative dimensions when biologically feasible. This may limit several restorative complexities. Matching wider crowns with a wider implant platform (and vice versa) results in a more biologically maintainable restoration and simplifies examination via peri-implant probing.17 A large mismatch between the crown and the implant body may lead to overhanging contours and an obtuse emergence angle, with all the associated negative biologic consequences (Fig 2c).

The vertical and horizontal position of the implant must synchronize with other key prosthetic and biologic factors to set the stage for success. For example, an obtuse emergence angle would be aggravated by a narrow-diameter implant if placed in a shallow position. It may be safer in this situation to place implants with narrower platforms slightly deeper (Fig 2d).
It is also worth mentioning that multiple studies revealed that tissue-level implants may not be as affected by changes in emergence angle as bone-level implants. In the case of tissue-level implants, this finding may be due to the contribution of a machined collar, which contributes to an increased distance between the crown-abutment margin and the alveolar crest. Increased abutment height may be considered to compensate for this if a bone-level system is used.

**IMPACT OF ABUTMENT HEIGHT ON MARGINAL BONE LEVELS**

The periodontal literature has historically reported that a minimum distance of approximately 2 mm from the restorative margin to the alveolar crest is indispensable for adequate formation of the supracrestal tissue attachment around teeth and maintenance of a healthy periodontium. It would seem logical to extend equivalent expectations toward implant restorations (Fig 3). However, several key differences between the peri-implant and the periodontal apparatuses make drawing parallels between the two fairly nebulous. The last decade was marked by a great interest in understanding whether abutment height may play a role in influencing MBL. Appropriate selection of abutment height is essential, allowing placement of the crown margin in a position that favors adequate formation of supracrestal tissue adhesion (STAd) or supracrestal tissue height and minimizes MBL. Many recent clinical studies have demonstrated a higher magnitude of peri-implant MBL when short abutments are used compared to longer ones.

Abutment height is often selected considering that the prosthetic margin should be placed at or slightly below the level of the peri-implant mucosa to support a cleanable and esthetic prosthetic design. It has been suggested that in cases of thick vertical mucosa (> 2 mm), abutment selection should consider establishing an adequate STAd (2 to 4 mm) to minimize the risk of MBL (Fig 4a). For equicrestal placement, a long abutment (> 2 mm) in the presence of thin vertical mucosa (< 2 mm) is contraindicated from an esthetic perspective due to the resulting supragingival position of the abutment-prosthetic margin, although minimal MBL will be expected (Fig 4b). Subcrestal placement in conjunction with a longer abutment may be implemented in this scenario. When thick vertical mucosa is present, equicrestal placement with a long abutment is preferred to minimized the extent of MBL, as if a short abutment is utilized, more MBL may be anticipated (Fig 4c). On the other hand, when thin mucosal height is present, the selection of a short abutment maximizes esthetics while compromising sufficient biologic dimensions for STAd formation. This potentially leads to greater MBL (Fig 4d). However, Linkievicius et al demonstrated that significantly greater MBL occurred when vertical mucosal thickness/supracrestal tissue height was ≤ 2 mm. Based upon this concept, some authors recommended soft tissue grafting procedures for augmenting vertical mucosal height at sites with a thin phenotype when shallow placement is necessary, although evidence in support of this is limited. Such procedures may permit selection of a longer abutment.

Vervaeke demonstrated that planning implant vertical positioning (ie, subcrestal or equicrestal) based on soft tissue thickness was highly successful in avoiding...
Saleh/Galli et al

Supracrestal tissue attachment (STA) Supracrestal tissue height (STH)

Sulcus
Junctional epithelium
Connective tissue
Supracrestal tissue adhesion (STAd)

Fig 3 Illustration of the biologic structures around teeth and implants. Supracrestal tissue attachment (STA) describes the periodontal attachment apparatus for natural dentition because it possesses perpendicular fibers that attach to the tooth structure. Two terms will be used to describe the peri-implant supporting tissues. Supracrestal tissue height (STH), also known as vertical mucosal thickness, consists of sulcular depth, junctional epithelium, and connective tissue adhesion (STAd). The second term is supracrestal tissue adhesion (STAd), which specifically refers to junctional epithelium and connective tissue adhesion. It is important to note that around implants, the term adhesion is more accurate than attachment, as fibers do not attach to the implant surface, but instead adhere due to their parallel orientation.

Fig 4 (a) Abutment height selection should be based on both apico-coronal implant positioning and mucosal thickness. Various articles have defined thin (≤ 2 mm) and thick (> 2 mm) vertical mucosal thickness (VMT).32,36 as well as tall (≥ 2 mm) and short abutment heights (< 2 mm).29,32,41 Scenarios a–d consider a clinical scenario involving equicrestal implant placement. a) In the presence of a thick VMT, a tall abutment height favors establishment of an ideal supracrestal tissue height (2 to 4 mm). In this case, minimal bone remodeling is expected. b) The selection of a tall abutment in the presence of thin VMT has also been associated with reduced bone remodeling in the literature.34 However, it should be noted that this scenario is not commonly implemented in clinical practice due to esthetic consequences associated with the supragingival position of the abutment-prosthetic margin. c) Choice of a short abutment height in the presence of a tall VMT is a poor clinical choice and will likely result in increased bone remodeling. d) The selection of a short abutment when thin VMT is present promotes esthetics but often leads to increased bone remodeling as a compensatory reaction. (e) In cases of thin VMT (such as in D), subcrestal placement may be utilized with bone-level systems to anticipate bone remodeling during establishment of STAd. This can potentially reduce the risk of implant thread exposure.
implant surface exposure. A similar concept was reported in a study by de Siqueira et al, where implants placed subcrestally with longer abutments (≥ 2.5 mm) did not exhibit thread exposure after 5 years of follow-up (Fig 4e). Subcrestally placed implants facilitate adequate distance for establishment of an ideal STA and may be associated with a reduced risk for thread exposure. This concept is valid for implants with abutment-fixture connections characterized by minimal micromovement. If an implant does not allow such features, MBL is expected to happen apical to the implant platform regardless of vertical implant position. The abutment height concept can be seen as the building block for analyzing outcomes of clinical studies reporting MBL. It should be noted that a key limitation of several studies on this topic was the absence of accurate soft tissue measurements.

Challenging the relationship between vertical mucosal thickness/supracrestal tissue height and marginal bone loss, Spinato and coworkers showed in a randomized clinical trial that implants restored with short abutments (1 mm) consistently demonstrated twice the bone loss of identical implants restored with long abutments (3 mm), irrespective of vertical mucosal thickness (groups with < 2 mm or > 2 mm). Clinically, the utilization of a long abutment (> 2 mm) may not be feasible if the implant is placed equicrestally in areas with thin vertical mucosal thickness due to the esthetic compromise. This would necessitate a more obtuse emergence profile and possibly expose the abutment surface above the mucosal margin.

Although the aforementioned evidence revealed the role of abutment height and supracrestal tissue height on MBL, long-term data on the effectiveness of this approach in reducing the risk of peri-implantitis is scarce. One consideration is that the deeper the position of the crown-abutment margin, the greater the prevalence of undetected cement. The authors reported that the greatest quantity of cement remnants was found when margins were positioned 2 to 3 mm subgingivally. Consequently, the balance between vertical implant positioning and abutment height must be considered to minimize the risk for retained cement after crown delivery.

**BIOLOGIC RESPONSE OF PERI-IMPLANT TISSUES TO SUBGINGIVAL CEMENT**

It has been well documented that subgingival cement remnants can contribute to the incidence of peri-implant diseases. Cement acts as a nidus for bacterial colonization, leading to inflammation in the peri-implant supporting tissues and in some cases to bone loss. The rough cement surface enhances biofilm adherence and impedes cleanability of the implant surface. The biologic mechanisms by which the retention of cement leads to peri-implant diseases remain unclear. Two possible explanations are that residual cement can cause mechanical irritation as well as induce a foreign body reaction in the peri-implant tissues. The mechanical irritation hypothesis resembles the scientifically validated concept of invasion of the STA by deep restorative margins. Future studies in this area are needed to validate these theories. Interestingly, the theory that initiation of peri-implantitis is primarily due to a foreign body reaction stimulated by both the surgical implant placement procedure and subsequent prosthetic rehabilitation, and not a biofilm-mediated inflammatory process, was presented by Albrektsson et al. During crown delivery, excess cement can potentially travel apically into the sulcus, following the direction of least resistance due to hydraulic pressure. Subgingivally retained cement around the natural dentition is an uncommon finding; this may be due to the fact that peri-implant probing depths are on average deeper than those around teeth, and key differences exist in the anatomy and physiology of the peri-implant and periodontal supporting tissues.

A distinction should be made between prospective articles reporting the prevalence of peri-implantitis around implants restored with cement- versus screw-retained crowns, and retrospective/cross-sectional studies investigating the proportion of diseased implants often displaying excess cement. This is important because in many studies cement-retained restorations were not found to be at a higher risk for peri-implantitis compared to screw-retained prostheses. This means that using a cement-retained prosthesis is not a risk factor, but its undetected invasion of the peri-implant sulcus promotes a chronic inflammatory response. Additionally, some studies analyzed excess cement by radiographic examination, which is an unreliable method. Indeed, two-dimensional radiographs do not allow detection of buccal and lingual excess cement and have limited capacity in the detection of interproximally retained cement.

There is limited evidence to support the notion that different cement properties may play a role in the biologic consequences of peri-implant subgingival retention. Indeed, methacrylate-based cements favor plaque formation, while zinc oxide–eugenol cements can dissolve over time and exhibit antimicrobial properties. Once subgingivally retained cement has set, it is difficult to remove. No difference in utilizing metal and plastic instruments has been seen in terms of cement removal efficiency, and both instruments may potentially cause damage to the implant surface.
TO SPLINT OR NOT TO SPLINT?

Splinting implant-supported prostheses is not always a straightforward decision and is a common source of debate among clinicians. On the one hand, it allows for a more even distribution of occlusal forces, leading to fewer prosthetic complications; on the other, maintenance of proper hygiene is more complex.62 Indeed, Serino and Ström reported that 4% of patients with prosthetic designs allowing adequate access for hygiene developed peri-implantitis, whereas patients without proper access developed peri-implantitis at 48% of sites. Interestingly, the majority of patients who presented with peri-implantitis exhibited a good level of plaque control for their remaining natural dentition.53 A long-term randomized clinical trial comparing three non-splinted implants versus three splinted implants reported no incidence of peri-implantitis during the follow-up period.64 On the other hand, in articles with a different methodology (retrospective and cross-sectional) that might better resemble daily clinical practice, a higher prevalence of peri-implantitis has been found for splinted implants, especially at the central implant, where access for hygiene is usually the most difficult.18,65

One of the important challenges for splinting multiple implants involves achieving a passively fitting superstructure. Increased plaque accumulation has been associated with clinical scenarios characterized by misfits between the implant and the overlying prosthesis.66 Misfits are also accompanied by a higher degree of stress at the bone-implant-prosthetic interfaces, which can lead to technical (ie, screw loosening or prosthetic fracture) and biologic consequences (ie, MBL).66 Clinical studies reported excellent outcomes when frameworks are cemented to prefabricated cylinders, as they exhibit precise adaptation to abutments or the implant platform, minimizing deformation of prosthetic materials inherent during laboratory steps.67,68 Today, with the introduction of digital technologies for impression making and prosthetic fabrication, the risk of misfit is expected to be reduced. Dental implant restorations fabricated digitally have been shown to be more precise than those produced by a casting technique.69,70 A recent clinical study on splinted restorations supported by two implants revealed that restorations fabricated digitally had a better fit on the control cast. However, no difference in passive fit was found intraorally.71 Due to the diversity of influencing factors and lack of reliable measures to evaluate the impact of misfit on biologic complications, there is no clear consensus on the “amount of fit” that is needed to prevent biofilm...
accumulation. The decision to splint or not to splint should take into account the need for an even distribution of occlusal forces to deliver a well-fitted restoration with a cleanable design.

ARE OCCLUSAL FORCES RELATED TO PERI-IMPLANT DISEASE PATHOGENESIS?

The potential influence of excessive occlusal forces on periodontitis and peri-implantitis is a controversial subject without clear evidence to support definitive conclusions. The 2017 World Workshop concluded that the evidence clearly demonstrates that occlusal trauma does not initiate periodontal disease, and that although a number of animal and clinical studies show an association between occlusal trauma and progression of periodontitis, the overall quality of this evidence is weak. \(^{72}\)

The biomechanical responses of teeth and implants to occlusal forces exhibit distinct differences due to how they are connected to the surrounding bone. \(^{73}\)

Before exploring the potential association between excessive occlusal forces and peri-implant disease pathogenesis, it is important to first understand how occlusal forces play a role in peri-implant bone remodeling in the absence of plaque-induced inflammatory disease. Establishment of osseointegration begins 2 to 3 weeks after implant placement, during which time there is a transition from primary (mechanical) stability toward secondary (biologic) stability as bone remodeling occurs. \(^{74}\) During initial healing, excessive micromovement due to either a lack of mechanical stability or the influence of occlusal forces may result in fibrous encapsulation and failure to achieve osseointegration (Fig 6a). \(^{75,76}\)

After secondary stability (osseointegration) is established, orthodontic-like forces have been demonstrated to directly impact peri-implant bone turnover and cellular activity, \(^{77}\) resulting in augmented peri-implant bone density near areas of moderate strain, whereas extreme values of either low or high strain resulted in reduced bone density. \(^{78}\) In an animal study, Lima and coworkers reported significantly increased radiographic and histologic bone density in response to excessive occlusal forces relative to unloaded implants and those with stable occlusal contacts. \(^{79}\) The same study also reported a higher incidence of screw loosening and abutment fracture in response to excessive nonaxial occlusal contacts, indicating that prosthetic complications are more likely in this scenario (Fig 6b). Studies investigating functional loading of osseointegrated implants with physiologic forces have corroborated these results, demonstrating increased bone-to-implant contact relative to unloaded controls. \(^{80}\)

If repetitive biomechanical forces are increased up to within a certain range, then this may result in net bone apposition as an adaptive response, enabling the bone to better deal with the increased stress. \(^{81}\) In rare cases of excessive occlusal load in a predominantly lateral direction, complete loss of osseointegration of dental implants has been reported, as in two animal studies conducted by Isidor, characterized clinically by mobility and peri-implant radiolucency, \(^{82}\) and histologically by fibrous encapsulation. \(^{83}\) In another study, excessive occlusal forces acting on osseointegrated dental implants with supraocclusal restorative contacts resulted in no significant differences in terms of bleeding on probing or pocket depth measurements, histologic bone-to-implant contact, marginal bone levels, or bone density relative to unloaded controls in the presence of adequate plaque control. \(^{84}\) Other work on static lateral forces has suggested that implant surface modifications may modulate stress transfer to the surrounding bone, with rough surfaces exhibiting a more favorable peri-implant bone reaction than machined surfaces in terms of bone-to-implant contact, bone density, and the propensity to develop vertical bony defects. \(^{85}\)

Implant length may also play a role in the response of peri-implant bone to functional loading. Human
clinical studies have demonstrated increased peri-implant bone density for short (6 mm) relative to long implants (10 mm) after 3 to 5 years of functional loading.⁶⁶,⁶⁷

Due to the ethical issues associated with conducting prospective human clinical studies analyzing the effects of occlusal trauma on plaque-associated peri-implant disease, the majority of relevant findings are based on animal studies or cross-sectional/retrospective analyses.⁴ Kozlovsky et al conducted a split-mouth study in beagle dogs with ligature-induced peri-implantitis on one side versus regular oral hygiene on the other.⁶⁸ Different abutment heights were used to create two loading conditions: supraocclusion and infraocclusion (unloaded). Thus, four clinical scenarios were present in each dog: unloaded inflamed, loaded inflamed, unloaded uninflamed, and loaded uninflamed. In the absence of inflammation, excessive loading significantly increased bone-to-implant contact in the unloaded uninflamed and loaded uninflamed groups, whereas in the presence of inflammation, overloading had no such effect, and an increased tendency for bone loss resulting in thread exposure was reported. Since crestal bone changes were not measured, it is difficult to extrapolate the data based on these results.

Dalago et al conducted a cross-sectional study in humans and found a significantly elevated risk for peri-implantitis by 2.4-fold if wear facets were found on implant-supported restorations.⁸⁹ Retrospective analysis of 332 implants placed in 56 patients with at least one implant diagnosed with peri-implantitis revealed a 15x higher prevalence of prosthetic complications such as abutment fracture, loss of retention, and chipping at sites with peri-implantitis compared to healthy sites.

Together, these findings suggest that in cases of progressive peri-implant MBL, the etiology is primarily microbial in nature with limited evidence to support the notion that occlusal forces act as a modifying factor (Fig 6c), although prosthetic complications are more likely when implants are subjected to excessive occlusal forces.

**LIMITATIONS**

It is important to note the limitations of this narrative review. Firstly, it would be ideal to conduct a systematic review and/or meta-analysis to eliminate potential bias or personal opinions; however, there is currently an insufficient number of randomized controlled trials available to allow for meaningful statistical analyses. Hence, one of the main goals of this manuscript is to stimulate more insightful research on the linkages between peri-implant health and prosthetic factors. Secondly, we did not address the potential complications related to implant-abutment mismatch, fixture/abutment fatigue fracture, or zirconia implant-related complications because we do not have adequate information to provide a meaningful assessment on these topics. Future studies in these topics are encouraged.

**CONCLUSIONS**

Current evidence shows that the prosthesis is significantly intertwined with the biologic response of the peri-implant supporting tissues. Each step of the restorative process is important in determining long-term prosthetic and biologic outcomes. These factors do not act in isolation but instead interact to directly influence biologic outcomes. Careful analysis and treatment planning are key to fabricating a prosthesis that is harmonious with a state of peri-implant health, allowing clinicians to take advantage of the prosthetic-biologic connection to decrease the risk for peri-implant diseases.

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