Review Article

Biomechanical Considerations and Occlusal Schemes in Implant Restorations; A Review, Part I: Fixed Prostheses

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Abstract

Background and Aim: The aim of this study was to gather available scientific data on appropriate occlusal scheme in each type of fixed implant restoration with the least adverse effect on implant and peri-implant tissues.
Materials and Methods: An extensive search was performed in PubMed, Scopus, Embase, and Google Scholar using related keywords. Studies related to evaluation of different occlusal schemes, and occlusion in implant dentistry were selected, reviewed, and discussed.
Results: The selected keywords yielded 995 search results in PubMed, 417 in Embase, and 500 in Scopus. After duplicate removal and title/abstract analysis, 83 studies were selected for full-text review. Finally, 43 studies met the requirement of inclusion/exclusion criteria and were included.
Conclusion: Selecting the right occlusal scheme for implant restorations is complex. Clinicians must consider multiple factors to prevent occlusal overloading. Following scientific guidelines ensures long-term success and predictability in implant-supported prostheses.
Key Words: biomechanics, implant occlusion, occlusal considerations, occlusal scheme, prosthetic considerations

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Introduction

Implant-based treatments are highly desirable for replacing missing teeth due to their high predictability and success rates. These treatments boast a success rate of over 80% for up to 16 years (1-4). Occlusion is an important factor in successful long-term serviceability of dental prostheses (1-3,5,6). Considering the lack of periodontal cushioning effect in implants, occlusion could even play a more important role in implant-based treatments, and in fact, is one of the most important determining factors in long run implant success (1,6) The effect of occlusion on long-term success returns to implant sensitivity to biomechanical stresses. (1-6) Occlusal stress has been suggested as one of the primary causes of biomechanical (e.g. screw loosening, implant component fracture, detachment of implant crowns) and biological (e.g. marginal bone loss) implant complications

(1,5-9). The role of occlusal overloading in biological implant failures is controversial. While animal studies have not confirmed this relationship, clinical studies have shown a clear correlation between parafunction and implant marginal bone loss (10-13). Applying correct occlusal patterns can assist clinicians in delivering long lasting and predictable treatments for their patients (1-3,5-10). Well recognized occlusal schemes with some modifications can be applied in implant dentistry (1-3,5-10) These modifications address implant sensitivity to lateral forces, lack of proprioception as a warning alarm in traumatic occlusal contacts in implants, and mechanical properties of dental implant systems (3,14,5-10) Since there is no acceptable codified conclusion available on proper occlusion types in fixed implant restorations, the present review study aims to suggest evidence-based occlusal schemes for different types of implant-supported fixed prostheses based on diverse scientific documents available.

Materials and Methods

A comprehensive electronic search was made using PubMed, Medline, Scopus, Embase, and Google Scholar from 1887 to 2020. The following keywords, with different combinations were searched in article titles, abstracts, or keywords: occlusal consideration, occlusal scheme, occlusal pattern, occlusion, occlus*, guidance, biomechanic, mechanical factor, dental implant, implant, and fixed prosthes*. Using reference management software (Endnote X8; Thomson Reuters), duplicated studies were eliminated, and articles were selected based on title-abstract analysis, followed by full text evaluation. Two independent reviewers evaluated the studies. In cases of disagreement, they engaged in discussions until consensus was reached. The included studies comprised peer-reviewed articles in the form of review articles, cohort studies, case-control studies, cross-sectional studies, case series or reports, and experimental studies. The included articles were selected in a way that they discussed occlusion in fixed implant prostheses, the consequences of occlusion and biomechanical forces on dental implants, and studies on stress profiles or occlusion principles in implant restorations. The studies focusing on removable restorations or tooth-supported prostheses were excluded. Animal studies were not also taken into consideration. The Data on the recommended occlusal schemes, and biomechanical principles and guidelines were extracted.

Results

The search results for the selected keywords yielded 995 published articles in PubMed, 417 in Embase, and 500 in Scopus. After duplicate removal and title/abstract analysis, 83 studies were selected for full-text review. Finally, 43 studies met the requirement of inclusion/ exclusion criteria and were included. Detailed information on search process is summarized in figure 1.

The articles showed extensive diversity in preferred occlusion for certain implant prostheses. To address this, the present study reviewed various suggested occlusal schemes and proposed the most prevalent or acceptable one. For proposing the most acceptable occlusion in such cases, the authors discussed and chose rational scheme based on the implant occlusion principles, and available finite element analysis or experimental studies which focused on stress distribution profile. Considering limited number of studies on this basic scientific field, the authors tried to subsume all the available evidence for implant-fixed prosthesis occlusion; although some of the evidences were not strong enough to be conclusive. The lack of adequate or strong scientific evidences for supporting specific occlusal scheme in some prosthetic type has been notified as “limited information”. These areas call for further research.

Discussion

Several occlusal schemes have been introduced for natural dentition, each with its own advantages and indications. These schemes will be summarized here based on the latest published terminology, as understanding this preliminary information aids in comprehending

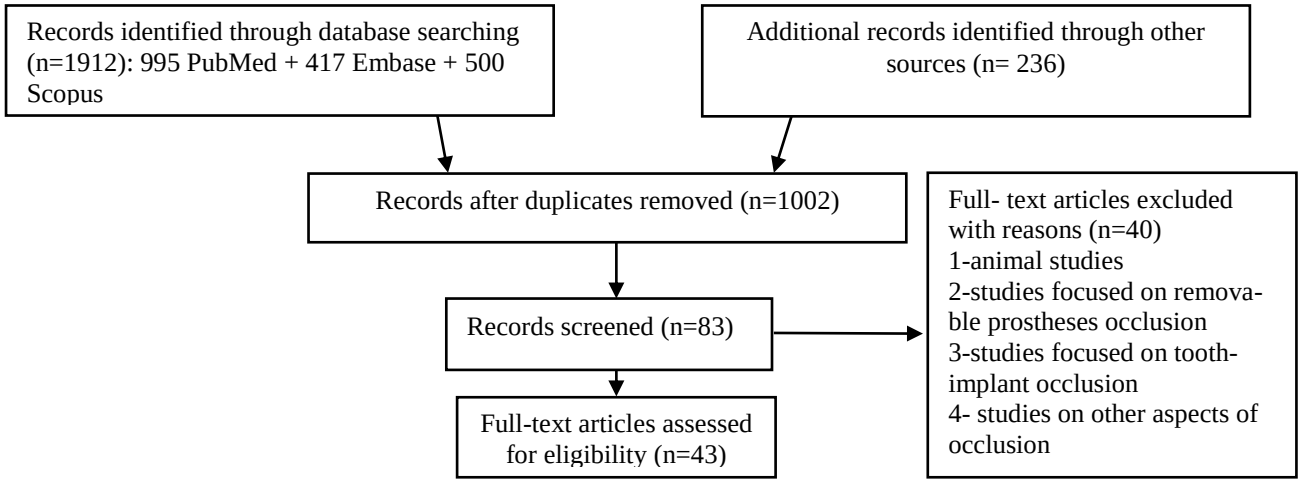

Figure 1. The study selection and identification chart

the content in a coordinated manner. Considering the specific requirements of implants, some of these patterns can be adapted for dental implants with certain modifications (3,14-21).

1- Mutually protected articulation (MPA) is characterized by mutual support: posterior teeth support the anterior teeth in maximal intercuspal position (MIP) while the anterior teeth maintain a clearance of 20-30µm. In turn, the anterior teeth separate the posterior teeth during all excursive movements (22,23). In classic form, incisors play the role of protrusive guidance, while canines guide the laterotrusive movements (24).

Canine protected articulation (CPA) is one of the deviations where canine teeth separate other teeth in all excursive movements (22-24).

Anterior protected articulation (APA) or anterior group function is another variation where canine and another anterior tooth (mostly lateral incisor) separate the posterior teeth in all eccentric movements (24).

2- Group function occlusion (GF) is another occlusal scheme where a group of posterior teeth play the role of guidance in lateral movements (22-24). When the anterior teeth are periodontally compromised, or could not guide the occlusion (e.g. anterior open bite or cross bite), the anterior-most posterior tooth plays the role of protrusive guidance (24).

3- Bilateral balanced articulation (BBA) is the preferred scheme for stabilizing removable full dentures in one or both arches. In maximal intercuspal position, there is no contact on anterior teeth. In eccentric movements, the teeth (two teeth or more in each side) share bilateral contacts in laterotrusive, or antero-posterior contacts in protrusive movements (22,23).

Lingualized articulation is one of subgroups where lingual cusps of maxillary teeth play the main role of centric and eccentric contacts to improve the load distribution and direction (25).

Implant-specified occlusion or implant protected occlusion (IPO), introduced by Misch (1) considers dental implant requirements in designing occlusal schemes. The differences mainly return to the lack of periodontal ligament in implants (1-6,22) that necessitates decreasing the occlusal loads and directing the forces along implants' long axes (1-6). The principles of implant protected occlusion could be summarized in the following considerations:

1- Any occlusal plane inconsistency should be corrected before impression (1).

2- Contacts should be centered in maximal intercuspation, with 1-1.5 mm freedom in centric (1,5,19,22).

3- Occlusal timing: In maximal intercuspal position there should be no or light contacts on

implants during light tapping, and identical contact on implant and adjacent teeth in heavy tapping (1,3,5,6,8,26). This principle should also be followed in eccentric movements where adjacent teeth are the main guidance and implant-contact happens just after completion of lateral movement of natural teeth. Timing returns to the difference between natural movability of implant and tooth.

4- The occlusal table should be narrower for implant restorations by reducing palatal contour of maxillary and buccal contour of mandibular restorations (1,5,8,15,22,26,27).

5- Incisal guidance angulation should be reduced to 23- 25 degrees on implants (5,21-23,28).

6- The cuspal inclination of posterior implant restorations should be reduced (1,5,8,15).

7-Point contacts particularly cusp-fossa occlusion is preferred on implant restortions (5,15).

After implant treatment, the patient's previous occlusion might be maintained or changed based on the number of replaced teeth, oral conditions, and occlusal stability (29-31). Considering the implants' characteristics and based on scientific evidence, it is preferred to disclude (D) implants by natural teeth contacts in all excursive movements, however, if this ideal scenario is not applicable, sharing (S) the discluding contacts on teeth and implants (with attention to timing in lateral movements), or splinted (S) implants could provide more predictable long-term results (1-3,5,6,7,14,15, 32). This concept will be referred to as DSS rule to facilitate explanation. DSS rule stands for: *d*isclude the implants by natural teeth *s*hare the discluding contacts between natural teeth and implants, or *s*plint the implants to predictably sustain the discluding role. Fixed implant restorations will be classified into single tooth, fixed partial restorations, full arch, and full mouth reconstructions to facilitate describing the preferred occlusion for each situation**.**

A. Single tooth implant restorations

For all single implant restorations, occlusal timing is necessary in maximal intercuspal position. In eccentric movements, the loads should be mainly sustained by adjacent teeth and patient´s existing occlusion should be followed (1).

A-1. Posterior or anterior single-tooth implant: Implant restoration should preferably be discluded during all eccentric movements, or participate in eccentric guidance, if necessary, following timing principle in lateral movements (3,5,6,8,26,27). The intensity of occlusal contacts could be gradually increased within 3 months intervals after restoration insertion (33) , since the occlusal force and contact time of implant prostheses will change significantly with time (34).

A-2. Canine single-tooth implant: Canine single implant is preferred not to burden the whole guide role in canine-raised occlusion (1). The preferred occlusion is mutually protected articulation (anterior protected) or group function, without canine participation (2,6,26). An experimental study has shown that group function occlusion produces less strain in canine implant restorations (35). In cases of inevitable canine engagement, the dentist should attempt to include at least one natural tooth, and take the advantage of natural proprioception (1,36). Anterior teeth, e.g. lateral incisors, are preferred since they are farther from the temporomandibular joint (1,24). During light lateral excursion, the periodontally healthy lateral incisor occludes first and moves 97 μm. Afterwards, canine implant engages and participates in posterior teeth disclusion (1). During heavy excursion, the natural teeth and implant crown contact with similar magnitude (1). However, in Angle's skeletal class II-division 1, anterior crossbite or open bite, the first premolar may need to be participated instead of lateral incisor (1,26).

B. Partially edentulous patients

For all fixed implant restorations inserted in partially edentulous jaw, timing is required in maximal intercuspal position or centric relation (1,32). In all eccentric movements, disclusion of implants is preferred. However, in inevitable participation, implants should follow the guidance provided by adjacent teeth under the timing principles, or be splinted together (DSS rule) (1,5,8,32). Although first proposed for removeable denture, Kennedy classification will be used in the following section to discriminate different situations (See figure 2).

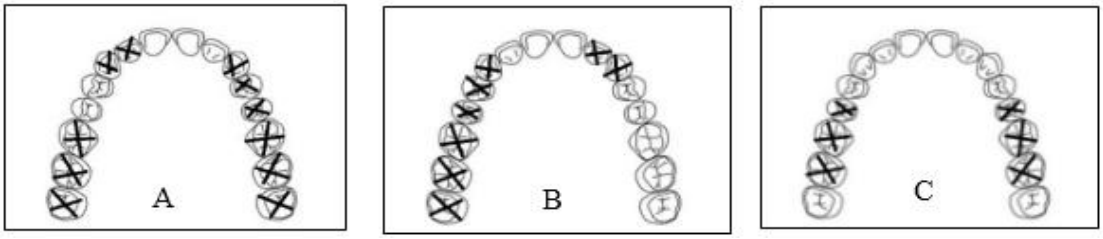

Figure 2. The examples of some different types of Kennedy classification: A. Cl I extended to anterior with anterior modification, B. Cl II extended to anterior with anterior modification, C. posterior cl III with posterior modification

B-1. Kennedy Class I: (bilateral posterior edentulism): When only posterior teeth are substituted by implants, mutually protected articulation on naturel dentition is strongly preferred (3,6,27). All movements are preferred to be guided by anterior teeth, and there should be no interference on implants in centric relation or eccentric movements (1,5,8). However, when posterior edentulism has been extended to anterior, or situations and prognoses of remaining anterior teeth do not let them separate implant restorations independently, the participation between teeth and implants could be helpful, and anterior and posterior group function could be used for protrusive and laterotrusive movements, subsequently (5,6,8,15,22,26,27,32). In extended posterior edentulism to anterior, implants' splinting or non-splinting will determine the occlusion. When the implants are splinted

together, mutually protected articulation is the ideal occlusion. When the implants are not splinted, group function or mutually protected articulation following DSS rule could be considered (5,6,8,15,22,26,27). When only anterior teeth are remained, the amount of centric relation clearance between anterior teeth in mutually protected articulation should be less than normal value (20-30 µm) since posterior implants are responsible for that, however, posterior clearance provided by natural dentition could be the same as normal or less, depending on remaining teeth situations (36-39). It has also been suggested to use cross bite occlusion in posterior implant restorations to minimize off-axis loads on implants (1,5,8,22,26)**.**

B-2. Kennedy Class II: The same principles as class I are applied for unilateral posterior edentulism.

B-3. Kennedy Class III: In this type (anterior or posterior edentulous areas surrounded by teeth), DSS rule is followed, with special emphasis on the priority of implant disclusion (32). The disclusion amount is determined by natural occlusal characteristics (6,27). However, 1.1mm posterior disclusion in protrusion, and 0.5 (for working side) to 1mm (for non-working side) clearance in lateral movements have been proposed as the least acceptable disclusion quantities (40,41). It is preferred to use the patient's previous occlusion. However, if canine has also been replaced by implant, the splinting condition plays the same role as Kennedy class I and II (1-9,14-24). A finite element analysis showed that using canine protected articulation in an implant bridge replacing canine and premolar teeth causes less overall stress (42).

B-4. Kennedy Class IV: Anterior edentulous area is restored by implant-restorations in this class. The anterior implants should have 30µm clearance in centric relation/maximal intercuspation, and should be supported by posterior teeth (mutually protected articulation) (6,8,26,27). The canine situation determines occlusal scheme in eccentric movements (26,43). If the canine is a natural tooth, mutually protected articulation (canine guided) could be the preferred occlusion (26,43). However, when the canine has been replaced by implant, anterior or posterior group function is preferred (2,6,22,26,43). Canine guided articulation could also be used if canine implant is splinted to the adjacent implants (26,43). Generally, the anterior guidance is

preferred over posterior guidance in all excuersions (2,3,8,26), provided that anterior implants are not overloaded (26,43). For this purpose, anterior guidance must be flatter than normal (less vertical, and more horizontal anterior overlap) (3,8,26,27), the amount of freedom in centric occlusion must be greater than normal (3), and the amount of disclusion should be less (0.8 mm for protrusive movement, and 0 (working side) to 0.4 mm (non-working side) for lateral excursions) (2).

Occlusal schemes for modification parts of partially edentulous patients (Figure 3)

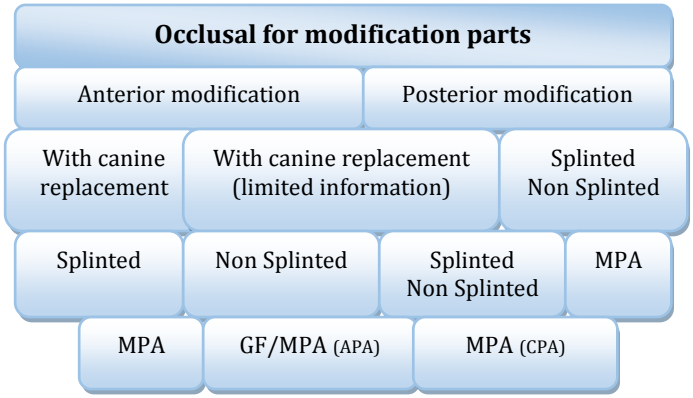

Figure 3. Occlusal schemes for modification parts in partially edentulous patients. MPA: mutually protected articulation, GF: group function occlusion, APA: anterior protected articulation, CPA: canine protected articulation

The edentulous areas separated from the main part will be referred to as "modifications" based on Kennedy's classification. Modifications are located more anterior than the main section, and therefore, they could be present in Kennedy's class I, II, or III, but not in class IV (44). The implant-supported fixed prostheses in modifications might have their own requirements and considerations for occlusion and there are situations where the occlusions have to be different in two sides of the arch. If a modification section is located in posterior part of the mouth, the ideal occlusal scheme will be mutually protected articulation on natural anterior teeth (2,5-8). However, for anterior modifications, canine situation is determinative. If the canine is not replaced by implant, mutually protected articulation (canine guided or classic type) is preferred (9,14,15). When canine is replaced by implant and the implants are splinted, mutually protected articulation (all types) could be an ideal occlusion. When the implants are not splinted in anterior canine containing modification part, group function occlusion and mutually protected articulation (anterior protected type) both have been suggested in different studies (20-23). In recent researches, mutually protected articulation is preferred not only for fixed restorations, but also for removeable dentures with evidences of improved masticatory efficacy, patient satisfaction, and reduced masticatory muscles activity that decrease the occlusal loading on the whole dentition (Table 1) (45-49). Therefore, this occlusal pattern will be preferred wherever it could be applied, provided that single implant does not guide the eccentric movements separately and DSS rule is followed for more predictability (2,3,5-9,14-16). There are limited evidence-based documents on occlusal scheme for modification parts of partially edentulism. These limitations have been considered in suggesting occlusal schemes in table 1, and strongly call for further studies.

C. Fixed full arch implant restorations

Timing in centric relation is not applicable when the whole arch has been restored by implants (1). The ideal occlusal scheme will be determined according to the opposing arch situations. When the implant prosthesis is opposed by removable full denture, bilateral balanced lingualized occlusion is preferred (5,8,15,22,26,50,51). However, recent studies have clarified that mutually protected articulation "promotes self-perception and has positive impact on masticatory function" even in complete denture wearers, that requires further evaluative researches (46,47). In the presence of removable denture in the opposing arch, maximal intercuspal position and centric relation should be coincident with no interferences in functional movements (5). To reduce the effect of non-axial forces, 1-1.5 mm freedom in centric has been suggested (5,22), the anterior guidance should be shallow (22), and identical intensity contacts in centric

Table 1. Summary of articles on comparing canine protected articulation (CPA) and bilateral balanced articulation (BBA) in removable prostheses.

Reference	Prosthesis type	Comparison	Duration	Conclusion
El-sadany HF, 2020[45]	Complete denture	BBA vs. CPA	1 months	Both occlusal schemes could be used effectively with no significant difference in masticatory function.
Brandt S, 2019 [46]	Complete denture	BBA vs. CPA	3 months	CPA occlusion offered significantly better retention, mastication, phonetics and esthetics.
Pero AC, 2019 [47]	Complete denture	BBA vs. CPA	1 month	CPA promoted self-perception of the patient, their ability to chew certain foods, and masticatory function
Lemos CAA,2018 [48]	Complete denture	Different occlusal schemes	Systematic review	CPA reduces muscular activity and should be used for complete denture.
Greco GD, 2008 [49]	Implant supported mandibular overdenture (RP5)	Different occlusal schemes	In-vitro	CPA should be the pattern of choice. BBA should not be applied.

relation and all movements should be considered on maximum participating implants (6,8,26). In the presence of natural dentition or fixed implant restorations in opposing arch, the ideal occlusion is mutually protected articulation. However, some researchers proposed group function occlusion (5,8,15,22, 26,52,53). The possible reason might be the angulation and smaller diameter of anterior implants, which make them more susceptible to loading during excursive movements. Nevertheless, according to a finite element analysis study, even in such situations, canine protected articulation produces less stress than group function (54).

D.Fixed full mouth implant rehabilitation

Timing in centric is not applicable, and mutually protected articulation is the option of choice for eccentric guidance in full fixed implant rehabilitations (2,6). Coincident centric relation and maximal intercuspal position (6), 30µm clearance for anterior restorations in centric relation, and shallow anterior guidance (2) should be considered. The suggested amount of disclusion is 1mm for protrusive movements, and 0.3 mm (in working side) to 0.8 mm (in non-working side) for laterotrusive movements (2).

There is conflicting evidence regarding the ideal occlusal scheme for full mouth implant restorations (55). According to the Miralles, canine-protected articulation has the same stress profile as group function, and both are acceptable schemes. However, a finite element analysis showed that group function is not appropriate for high stress production, while canine protected articulation causes the lowest stress value during lateral movements (56). It is a reasonable occlusal scheme for full mouth fixed implant restorations.

Occlusion is an important determinative factor for long-lasting success of implant treatments. Selection of appropriate occlusal scheme in each of the implant prosthetic options is challenging. This review study tried to gather available diverse evidences to facilitate this decision-making challenge. Table 2 shows the summary of occlusal considerations in implant fixed prosthetics.

Table 2. Summary of articles on occlusal considerations in fixed implant restorations. BBA: bilateral balanced articulation, MPA: mutually protected articulation, CPA: canine protected articulation, GF: group function occlusion.

Reference	Prosthesis type	Comparison	Study type	Conclusion
Seifi M, 2017 (61)	Full mouth fixed implant restorations	GF vs. MPA	In vivo: Not mentioned	MPA showed lower Masseter and Temporalis muscles contraction
Hasan I, 2014 (59)	Long span cement able fixed implant prosthesis	Splinting vs. non-splinting	In-vitro: finite element analysis	Splinting reduced the stresses on cortical bone
Gore E, 2014 (64)	Fixed partial denture supported by implant	GF vs. CPA	In-vitro: finite element analysis	CPA had less functional loading on implants
Teixeira FM, 2012 (58)	2 implants in second premolar and molar	Different force magnitude: 300,600 and 900 N	In-vitro: photoelastic model	Splinting the crowns of adjacent implants decreases the stress especially in 600 N of load.
Yokoyama S, 2005 (62)	Mandibular bone supporting a single or separate multiple implant-superstructures	Splinting vs. non-splinting CPA vs. GF	In-vitro: finite element analysis	Splinted crowns had lower stresses in the peri-implant bone. CPA had lower stresses in working side implants.
Guichet DL, 2000 (57)	Implant supported crowns	Splinting vs. non-splinting	In-vitro: photoelastic model	Splinted restorations exhibited better load sharing compared to non-splinted ones.
Apicella A, 1998 (60)	Mandibular fixed full arch	MPA vs.GF	In-vitro: finite element analysis	GF had less stress intensity on the cortical bone
Hobkirk JA, 1996 (63)	Mandibular implant supported bridges (All-on-3, All-on-4)	GF vs. BBA	In vivo: 6 months	BBA had lower mean peak masticatory force

All the occlusion terms have been derived from the latest version of the Glossary of Prosthodontic Terms to facilitate understanding (65).

Although preferred occlusal scheme for each prosthetic situation has been proposed based on available literature and evidence, there is a severe lack in clinical studies or even evaluative in-vitro researches on long-term effects of these occlusal schemes on implant, restorations, and surrounding tissues. Since occlusal loading plays an effective role in implant successful serviceability, evaluative studies on this basic other encountered limitations were the inconsistency and incoherence in review articles, inadequate studies on this topic, lack of clear guidelines for choosing appropriate implant occlusion in different clinical situations, the complexity of occlusion concept, and the differences between implant and tooth occlusal requirements. The present review tried to collect available scientific documents and help the clinicians organize the diverse data for sound decision making on occlusal scheme selection. However, this review focused on normal situations, while there are several

compromised situations that call for further studies. Abnormal occlusal patterns namely excessive horizontal or vertical overlap, Angle's class II or III classification, cross-bite, or open-bite may affect the selection criteria of occlusion as well as abnormal conditions such as periodontally compromised teeth, horizontal or vertical cantilever on implants, and patient special parafunctional habits. All these fields could be attractive goals for researches warranting further studies.

Conclusion

Occlusion plays an important role in prosthetic and implant complications and failures. Considering the differences between implant and natural tooth, occlusion could even be more determinative in long-term serviceability of implant-based fixed prostheses. DSS rule (disclusion, sharing, splinting) has been introduced based on available evidence to facilitate decision making in a variety of clinical situations. Understanding and applying correct occlusal principles and patterns are critically important for any clinician, especially given the increasing use of implant restorations.

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