Review

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Review

Personalized Occlusal Scheme: Occlusion and Biomechanical Risk Factors in Implant-Supported Complete Fixed Dentures. Narrative Review

Andrea Berzaghi [1,*], Tiziano Testori [2,3,4,5], Riccardo Scaini [2,3] and Sergio Bortolini [1]

[1] Department of Surgery, Medicine, Dentistry and Morphological Sciences with Interest in Transplant, Oncology and Regenerative Medicine, University of Modena and Reggio Emilia (UNIMORE), Modena, Italy; sergio.bortolini@unimore.it
[2] IRCCS Galeazzi S.Ambrogio Hospital, Dental Clinic (Dean: Luca Francetti MD, DDS), Section of Implant Dentistry and Oral Rehabilitation (Head: Tiziano Testori MD, DDS, FICD), Milan, Italy. tiziano.testori@gmail.com (T.T.); riccardoscaini@icloud.com (R.S.)
[3] Department of Biomedical, Surgical and Dental Sciences, University of Milan, Milan, Italy
[4] Adjunct Clinical Associate Professor, Department of Periodontics and Oral Medicine, School of Dentistry, University of Michigan, Ann Arbor, MI, United States.
[5] Department of Oral Medicine, Infection and Immunity, Harvard University, School of Dental Medicine, Boston, MA, United States.
* Correspondence: andrea.berzaghi@unimore.it

Abstract: The biophysiological differences between teeth and dental implants and the issue of occlusal overload, although controversial, form the basis for the management of occlusion in implant-supported fixed complete dental prostheses (IFCDPs). Although occlusion management is currently lacking in scientific evidence, it is nevertheless evident that the favorable prognosis of IFCDPs is linked to a correct understanding of the biomechanical principles involved. In the design of IFCDPs, the lack of proprioceptive feedback requires special attention to biomechanical factors: minimizing overload complications and conferring biomechanical stability are among the main goals of occlusion. In IFCDPs, the occlusion has to be decided on the basis of several factors affecting the loads on prosthesis and implants: each case has to be evaluated individually and needs a customized occlusion. The main goal of this narrative review is to provide an overview of the occlusal principles and materials that can be used in IFCDPs based on the data currently available in the literature. The research proposes practical clinical recommendations for the occlusion management of IFCDPs and a biomechanical risk score index aimed at customizing implant-prosthetic treatment.

Keywords: implant-supported complete fixed dentures; occlusion; occlusal scheme; occlusal overload; occlusal materials; personalized occlusion; biomechanical risk factors

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1. Introduction

Edentulism is a debilitating and irreversible condition and is described as the 'ultimate marker of disease burden for oral health' [1]. Moreover, it is associated with deterioration of patients' quality of life, loss of self-esteem and potential repercussions on patients' life expectancy [2–4]. Implant-supported fixed complete dentures (IFCDP) represent the gold standard of care and aim to restore the aesthetics and function of edentulous patients, enabling them to improve their oral health and return to their normal lifestyle [3–6]. Several studies have documented a favorable long-term prognosis, showing high implant survival rates [7–9]. IFCDPs, however, may present prosthetic and biological complications induced by several variables including occlusion: occlusal design, the number and distribution of occlusal contacts, framework design, the type of antagonist arch, and the presence of parafunctions are among the variables that may condition the biomechanical stability of implant-supported rehabilitation [10–13]. The issue of occlusion in IFCDPs is as debated as it is complex as it involves surgical and prosthetic aspects that require careful planning and design. In IFCDPs, decisions about prosthetic occlusion include the choice of materials, the selection of implant-prosthetic design and the definition of distribution and intensity of occlusal contacts. The different biomechanics between teeth and implants makes occlusal design complex: achieving proper occlusion requires understanding the biophysiological differences between natural teeth and implants, as well as recognizing the role potentially played by occlusal overload in the development of prosthetic and biological complications. These concepts form the basis for the occlusal strategies in IFCDPs and for the selection of appropriate occlusal materials. For the realization of IFCDPs, clinicians have a wide range of combinations of prosthetic materials available which are selected on the basis of clinical criteria and on the basis of the patient's economic availability. To select the most advantageous implant-supported solution, it is crucial to know the strengths and weaknesses of the available options. Knowledge of occlusal concepts, occlusal materials and occlusion-related risk factors influence the longitudinal prognosis of implant-supported restorations [14]. The aim of this study is to provide an up-to-date overview of occlusal principles and materials that can be used in IFCDPs based on currently available data in the literature. The research proposes practical clinical recommendations for the management of occlusion in IFCDPs and a biomechanical risk score index aimed at personalizing implant-supported treatment.

2. Differences between Teeth and Dental Implants

The biophysiological differences between a natural tooth and a dental implant are well established [11]. The direct structural and functional connection between bone and titanium implant surface is known as osseointegration and represents a stable biological basis to support the prosthetic restoration [15]. Unlike natural teeth, osseointegrated implants are anchored to the bone without the periodontal ligament apparatus that biologically provides mechanoreceptors and functional shock absorption. This results in substantial differences between teeth and implants in load perception and modulation mechanisms and in terms of stress distribution where implants show reduced resilience and load absorption capacity. Teeth are endowed with high proprioception, with an ability to perceive occlusal thickness quantifiable at around 20 μm [11,12,16]. In contrast, with implants this is lower: the perception capacity between tooth and implant is about 48 μm; between two implants it is about 64 μm; while in the case of implant-supported overdentures it increases to about 108 μm [11,12,16]. Furthermore, implants and teeth under load react differently. In the tooth, the periodontal ligament due to its viscoelastic properties acts as a shock absorber under loading, allowing axial movement of approximately 25-100 μm and horizontal movement of approximately 50-100 μm. Loading on the implant, due to viscoelastic properties of the bone, can induce axial movement of approximately 3-5 μm, while horizontal implant movement can reach 10-50 μm [11,12]. The implant reacts to the load to the extent allowed by the elastic deformation of the alveolar bone. Indicatively, a light force (20 N) can intrude a natural tooth by about 50 μm compared to about 2 μm in the osseointegrated implant [17]. In the implant, horizontal forces are concentrated more at the level of the peri-implant crestal bone, opposing rotation [11,18]. In IFCDPs, the lack of shock-absorbing function due to compressibility and deformability of the periodontal ligament of the natural tooth results in significant differences in adaptation to occlusal forces. Furthermore, while natural teeth have neuromuscular and proprioceptive mechanisms to protect themselves from damaging forces, there is no equally effective mechanism for implant-supported prostheses. The periodontal ligament of natural teeth is able to provide the central nervous system with feedback for sensory and motor control unlike implants that only have feedback from distant mechanoreceptors resulting in decreased tactile sensitivity [19]. Natural teeth have periodontal mechanoreceptors and proprioceptive and neuromuscular mechanisms that can provide feedback for sensory and motor control to protect against occlusal overload. Adequate sensory information from periodontal mechanoreceptors is essential for normal control of contact and chewing forces [20]. In IFCDPs there is a complete absence of periodontal ligament mechanoreceptors and related proprioceptive input. The reduced tactile sensitivity of the implants may result in reduced coordination of the masticatory muscles and increased susceptibility to occlusal overload [21]. Without a periodontal ligament, the occlusal loads of the implant-supported prosthesis are transferred directly to the bone, predisposing, according to some authors, to biological complications [19]. Despite these differences between tooth and implant, several studies support the existence of a compensation phenomenon termed 'osseoperception' that represents the mechanism underlying the functional integration of the dental implant [22]. The term osseoperception has become widely associated with occlusion in cases of implant-supported restorations and indicates that biological compensation process capable of restoring sensory feedback after implant-supported oral rehabilitation. Functional integration of IFCDPs is based on osseoperception, which can be defined as physiological compensatory adaptation promoted by mechanical stimulation of implants. With the loss of teeth and periodontal structure we see the loss of mechanoreceptors and proprioceptive and neuromuscular mechanisms capable of providing feedback for sensory and motor control to protect against occlusal overload. In spite of this, other receptors, both proximal and peripheral, seem to take over and are responsible for a physiological compensatory adaptation promoted by the mechanical stimulation of the implant that approaches natural sensitivity [23]: the mechanoreceptive function seems to be evoked by receptors in the osseous, periosteal and peri-implant periodontal tissues, and by peripheral receptors at the level of the masticatory muscles and the temporomandibular joint. These provide mechanosensory information in relation to the jaw function and occlusal contacts of implant restorations. The tactile sensitivity provided by the osseoperception mechanism, although not identical to the original, would appear to be qualitatively and quantitatively sufficient to ensure the ability to adapt to occlusal loading and modulate motor activity, even in the peri-implant region [22]. Furthermore, with time, the perception of occlusal contact with implants is likely to improve due to the biological and psychological plasticity of the somatosensory cortex [23,24]. One study reported a significant improvement in osseoperception on implants after 3 months of healing, supporting the compensatory role of other receptors [24]. However, it is unclear whether the level of perception of implants completely returns to that of natural teeth over time [25]. Failure to achieve optimal osseoperception may expose to overload and complications related to excessive occlusal forces that the patient is unable to perceive correctly in the absence of restored neurosensory function [22]. In this clinical scenario, prosthetic occlusion must be designed to preserve the IFCDPs from excessive occlusal loads potentially favored by loss of proprioception.

3. Occlusal Overload and Dental Implants

Knowledge regarding the relationship between peri-implant disease, dental implant survival rate and occlusal overload is currently limited and lacking in scientific evidence [25]. Occlusion is a known contributing factor to the occurrence of prosthetic complications. However, some authors believe that occlusion also plays a role in biological complications of dental implants. The most common biological complications in implant-supported restorations are peri-implant diseases, particularly mucositis and peri-implantitis [26]. Although success rates of implant-supported restorations are high, some authors identify peri-implantitis and occlusal overload due to incorrect occlusion as the main causes of late implant failure [27]. Peri-implantitis is defined as 'a plaque-associated pathological condition occurring in tissues around dental implants, characterized by inflammation in the peri-implant mucosa and subsequent progressive loss of supporting bone' [28]. Current literature has attempted to identify factors that may increase a site's susceptibility to peri-implantitis by identifying five factors in implant design, implant site, prosthesis, and operator- and patient-related variables that may have a synergistic effect on the overall host response to bacterial plaque at implant sites [29]. In addition, there has recently been increasing evidence indicating that some peri-implant inflammatory conditions may not be primarily related to biofilm-mediated infectious processes, but rather to other biological mechanisms, such as foreign-body response [30]. Some authors consider the presence of wear facets on implant-supported rehabilitations as risk indicators for peri-implantitis [31]. Occlusal overload is the application of excessive force on an implant, either through normal function or parafunctional habits, resulting in structural or biological damage [32]. The absence of a periodontal ligament can make dental implants more vulnerable to occlusal overload: lacking periodontal receptors, they have a reduced capacity for load sharing, adaptation to occlusal forces and mechanoreception, which makes them more susceptible to overload [11]. Furthermore, in implant-supported restorations, the shock-absorbing function given by the compressibility and deformability of the periodontal ligament of the natural tooth is lacking. According to proponents of a cause-effect link between overloading and biological complications, the presence of peri-implant bone loss is attributable to the presence of occlusal overload. Excessive occlusal loading on implant-supported restorations results in increased stresses on prosthetic components and peri-implant bone tissue, particularly in the marginal bone ridge region [11]. This mechanism represents a potential cause of prosthetic damage or peri-implant bone loss and is therefore unacceptable for both technical and biological reasons [33,34]. Peri-implant bone loss is a complex phenomenon in which the bacterial component is relevant but is often associated with other factors [35]. In addition, local and individual factors can influence the strength of osseointegration, and therefore the biological effect of occlusal loading is highly variable [36]. Several studies have been conducted to evaluate the impact of overload on peri-implant tissues. However, the link between overload and peri-implant tissue loss remains controversial due to the limited number of clinical studies and the difficulties in conducting randomized controlled trials in humans [29,37,38]. Most data on the relationship between occlusal overload and peri-implant bone loss come from animal studies, with their limitations and conflicting results. While occlusal overload appears to play a role in the development of peri-implant disease in the presence of inflammation, this association is not observed in cases where the peri-implant tissue is clinically healthy [38–41]. Although the data are contradictory, potential deleterious effects of occlusal loads on peri-implant crestal bone cannot be excluded [35]: reasonably, occlusal overload can be understood as a predisposing factor for peri-implant disease in the presence of plaque and inflammation [29,38]. Occlusal forces on implant restorations are dynamic and multidirectional [42] and can be influenced by individual factors [43,44]. Some authors argue that the intensity, frequency and duration of occlusal loading can lead to pathological overloads that exceed the physiological tolerance threshold of the bone, causing microfractures at the bone-implant interface [19]. In addition, the intensity of loading can influence the bone's response: Frost's mechanotactic theory [45] considers loading an actor capable of producing different effects on bone depending on the level of micro deformation produced: micro deformation values above 3,000 micro strain (με) are considered overload, resulting in a catabolic bone response. Melsen and Lang, in contrast, observed that bone resorption occurs above 6700 με [46]. The issue of the load threshold value capable of triggering peri-implant bone loss remains complex and still theoretical, without definitive answers and difficult to relate to clinical reality [47]. Despite conflicting opinions on the cause-and-effect relationship between overload and peri-implant disease, there is evidence that occlusal overload is one of the main causative factors of technical and mechanical complications affecting the prosthesis and supporting implants [38]. In addition to causing fracture of the occlusal materials of the restoration and structural failure of the prosthesis, overload can induce loosening and fracture of the connection screw and also implant fracture [14,38]. Implant fracture is the apparently less frequent but most feared complication. Function over time can compromise implant integrity by triggering ‘cracks’ that can accelerate or trigger peri-implant bone loss, resulting in exposure of the implant neck and coils [21]. In this regard, in a study of implants failed due to peri-implantitis, implant fatigue cracks were found in particularly high percentages [48]. These data confirm that there is still a poorly delineated link between overload, mechanical complications and biological complications and that the topic needs dedicated studies. In spite of the ambiguity of the link between occlusal overload and peri-implant bone loss, the occurrence of both technical and mechanical prosthetic complications in IFCDPs should be noted and not underestimated because they may be alarm bells for more important consequences: they may represent clinical signs predictive of potential biological complications. Frequent loosening or fracture of connection screws as well as peri-implant bone loss are characteristic signs that may precede implant fracture [49]. It is important to note that complications are often interconnected. As stated in a recent review, there is a bidirectional positive feedback between biological and prosthetic complications, implying that prosthetic complications can lead to biological complications and vice versa [50]. There are numerous factors and clinical scenarios that may contribute to occlusal overload and have a negative impact on the longitudinal prognosis of IFCDPs: improper occlusal scheme or occlusal design, premature contacts, unbalanced static and dynamic occlusal contacts, insufficient passive fit of the prosthetic framework, long cantilevers, parafunctional habits. In addition, other biomechanical variables not strictly related to occlusion may influence the distribution of masticatory forces to the implant: bone quality and quantity; implant length, implant diameter and its macro- and micro-topography; number and position of fixtures; type of prosthesis; prosthetic material; type of implant connection [51]. Regarding the number of implants in IFCDPs, 6-8 implants in the maxillary upper jaw and 4-8 mandibular implants are considered acceptable [12]. Regarding bone quality, this should be considered a critical factor in the success of implant treatment. A 20-year retrospective clinical study found that implants placed in type I bone demonstrate the lowest failure rate compared to other bone types [52]. Several studies have reported that the failure of implants in the posterior upper jaw is related to the bone quality of that area [53]. In addition, the combination of occlusal overload and poor bone quality has been considered a relevant factor in late implant failure [54]. The results of recent systematic reviews show that reducing occlusal overload contributes to favorable prognosis of prostheses and implants [14]. The suggestion is to optimize implant-prosthetic occlusion in terms of load distribution and occlusal stability to minimize complications and ensure long-term biomechanical stability to the restoration [27,38].

4. Bruxism

Bruxism, characterized by involuntary clenching and grinding of teeth [55] is a parafunctional activity that increases the risk of prosthetic and biological complications in implant-supported restorations. Depending on the area of the oral cavity and patient characteristics, occlusal forces vary considerably. The magnitude of occlusal loads varies from 100-250 N at the level of anterior teeth, to 300-800 N in posterior sectors. The highest load levels are generally attributable to parafunctional habits with maximum values even exceeding 800 N at the level of the first molar [56–58]. In addition to generating higher forces, bruxer also outperform non-bruxer in terms of frequency of contact [19,59,60]. In cases of IFCDPs, the lack of proprioception typical of the absence of the periodontal ligament may amplify parafunctional activity [19]. In extensive prosthetic rehabilitations, bruxism can significantly contribute to implant fractures, peri-implant marginal bone loss, and subsequent implant failure [61–63]. From 20% to 35.9% of patients can generate forces of such magnitude that they cause microfractures of the bone around the implants with concomitant bone loss and implant failure [19]. A study of bruxer and non-bruxer patients reported an association between bruxer and implant failure with an odds ratio of 2.71 [64]. In addition, a recent study reported implant survival rates in bruxer at 5 years: 90% after 1 year, 87% after 2 years, 85% after 3 years, 75% after 4 years, and 72% after 5 years [65]. In another study on implant fracture, 90% of fractured implants occurred in cases of parafunctional patients and with cantilever prostheses [49]. Despite inconclusive evidence, these studies require the clinician to preserve the implant-prosthesis from bruxism-induced loads. Devices such as occlusal splints are routinely used to reduce the potential damage caused by bruxism on both natural dentition and implant restorations [38]. Although the use of occlusal splints in the treatment of nocturnal bruxism is not supported by scientific evidence and their efficacy in reducing nocturnal muscle activity remains unclear, these devices allow for a more even distribution of occlusal forces, prevent unfavorable loads, and preserve the occlusal material of the restoration from fracture and wear mechanism [61,66,67].

5. Cantilever

The distal cantilever, which in IFCDPs has a long history of clinical success, in cases of limited prosthetic space or parafunctional habits represents one of the prosthetic components at highest risk of mechanical complications [68,69]. A recent study confirms that in zirconia-ceramic and titanium-ceramic IFCDPs, the presence of cantilever is associated with increased prosthetic complications [70]. In addition, the cantilever is a design component that can generate occlusal overload and stresses on implants, especially on those closest to the extension [19,71]. The cantilever is a source of biomechanical stress: it functions as a class I lever and subjects the implants, implant-prosthetic connection, and peri-implant bone to alternating tensile and compressive stresses during function [72]. Increasing cantilever length results in exponential growth in stress levels: some authors consider excessively long cantilevers to cause peri-implant bone loss and prosthetic failure [73–75]. The length of the cantilever should not exceed 15 mm at the mandibular level and 12 mm in the maxilla [11,71,76]. However, in order to prevent potential complications some authors consider it prudent to design cantilevers no longer than 8 mm [77]. However, there are factors that may influence the choice of cantilever length. The presence of more splinted implants might allow an increase in cantilever length [78,79]. Conversely, fewer implants result in more disadvantageous bending forces [74]. According to some authors, proper implant placement, shorter cantilevers, and the use of long implants may be effective strategies in preventing complications [10]. In IFCDPs with cantilevers, the presence of distal tilted implants has demonstrated better stress distribution on posterior implants than rehabilitations with straight implants [80]. In all-on-four zirconia solutions, shortening the cantilever and increasing the tilt of the posterior implants to 30° seems advantageous in terms of load distribution [81]. A recent FEM study suggests 9 mm cantilever in the presence of distal tilted implants in cases of mandibular monolithic zirconia rehabilitations [82]. Historically, the A-P spread has often been used to determine cantilever length in IFCDPs. The A-P spread is defined as the distance between the center of the most anterior implant and a line joining the distal margins of the two posterior implants: the distal cantilever should remain in a 1.5:1 ratio with the A-P spread. The A-P spread method, however, is not validated by scientific evidence and is only one aspect to consider when determining cantilever length [83]. According to several authors, the cantilever should be designed in sub-occlusion (clearance) of about 100 µm to prevent unfavorable loading and fracture risk [11,17,84]. In addition, no contact on the working and balancing side should be provided on the cantilever during lateral excursions: lateral and protrusive excursions should provide for cantilever disocclusion [11,17]. Although generally, IFCDPs show higher rates of complications in antagonism with natural teeth or fixed restorations [13], some authors point out that even higher loads can develop when cantilevers are in antagonism with removable complete dentures [17]. There are numerous studies on posterior cantilever, but few data are available on anterior cantilever. In edentulism, inter-arch relationships are often compromised by the dynamics of bone resorption, which forces an implant-prosthetic design with anterior cantilever and vestibular over contour to compensate for the sagittal discrepancy between the mandible and upper jaw. The maxillary upper jaw is usually more exposed to this prosthetic design conditioned by the need to position incisal margins according to esthetic, phonetic, and occlusal criteria. In the presence of anterior cantilever, a greater antero-posterior distance between the more distal and more anterior implants may be advantageous to compensate for increased excursion loads. Brosky's study of mandibular implant-supported rehabilitations with anterior cantilevers of 5.9 to 14.4 mm found no significant correlations between anterior cantilever extension and peri-implant bone loss [72].

6. Occlusal Materials

The first occlusal material introduced for IFCDPs was acrylic resin: according to Branemark's original protocol, IFCDPs involved cast gold frameworks combined with acrylic resin and acrylic teeth. Later, the costs of gold led to the use of alternative alloys such as silver-palladium, titanium or chromium-cobalt. In the past, acrylic resin was believed to provide a “shock-absorbing effect” on implants that could offset the resilience of the periodontium and allow the occlusal surface to be the weakest link in the implant-prosthetic restoration. The aim was to provide a shock-absorbing effect to reduce overload and the probability of implant failure [85]. However, this “shock protection concept” belonged to the early design concepts of IFCDPs. Over the years, aesthetic demands and other priorities have led to the introduction of alternative materials. As knowledge about osseointegration and the evolution of materials and implant-prosthetic design has deepened, the use of metal-ceramic systems has become widespread [86]. The combinations metal-acrylic resin, metal-composite resin, (in this case the prosthetic teeth are composite) and metal-ceramic represent the most traditionally used materials in IFCDPs. The combination of metal framework and acrylic resin teeth has demonstrated high success rates [87]. The strengths of this still popular solution are its simplicity, low cost, easy repair management, long tradition, and clinicians comfort level acquired over the years by clinicians [88,89]. Alternative solutions represented by metal-composite resin and metal-ceramic are more expensive, more labor-intensive to fabricate, difficult to repair, and subject to fabrication techniques [86,89,90]. IFCDPs in standard materials have several complications in the short and long term, including marked wear of acrylic resin, fracture or detachment of resin teeth, chipping and fracture of the ceramic veneer in functional areas, lack of passive fit, difficulty of color rendition of gingival pink, and expensive prosthetic repairs [86,89,91,92]. The presence and length of cantilevers, lack of fine proprioception, type of antagonist, parafunctional overload, and poor adhesion of ceramic veneers are the main risk factors associated with complications of these rehabilitations. Higher rates of prosthetic complications occur in cases of IFCDPs antagonized with natural teeth or fixed restorations [13]. Specifically, metal-acrylic resin IFCDPs require five to six maintenance procedures in 10 years, with higher numbers in cases of bimaxillary rehabilitations [89,91]. To overcome the limitations of traditional materials, the evolution of CAD-CAM technology enabled the introduction of zirconia-ceramic systems for screw-retained implant-prosthetic frameworks [93]. In subsequent years, advances in zirconia-based materials in terms of aesthetics and the need to resolve technical complications mainly related to chipping of the ceramic veneer led to the introduction of monolithic zirconia frameworks [86]. IFCDPs in monolithic zirconia represents a promising solution that not only presents high biocompatibility and encouraging reliability data in the short and medium term, but also leads to a reduction in prosthetic design complexity, offering undeniable fabrication advantages [94]. There is currently no scientific evidence to support a link between the type of occlusal material and implant osseointegration. The choice of occlusal material appears to be irrelevant in terms of the transmission of forces to the implants [95]. Furthermore, there appears to be no difference between occlusal materials in terms of stresses transmitted to the bone [96]. For a favorable longitudinal prognosis of IFCDPs, regular occlusal checks are recommended to ensure contact stability and proper load distribution [38,97]. In this sense, the choice of occlusal material leads to important differences in the management of the implant-supported restoration over time. In particular, occlusal surfaces made of resin, composite, glass-ceramic, and zirconia experience different occlusal wear with function and exert equally different abrasive wear on the antagonist [98]. Therefore, in the decision-making process of prosthetic materials, it is imperative to consider the wear properties of restorative materials and the presence of parafunctions. Based on the previous considerations of occlusion and occlusal morphology, occlusal materials with high levels of wear such as acrylic resin may not be suitable for definitive IFCDPs because they would render all reasoning regarding occlusal patterns, chewing efficacy, and occlusal stability futile.

7. Personalized Occlusion and Biomechanical Risk

Despite the great popularity of implantology, there persists a low level of scientific evidence on how to manage occlusion in cases of IFCDPs such that the topic is still a challenge for clinicians. Currently, decisions are made based on expert recommendations and clinical experience. Current concepts are based on those developed for removable complete dentures and fixed prosthodontics on natural teeth. Many authors apply a logical and practical approach to achieve the primary goal of occlusal therapy in IFCDPs: comfort, chewing function, and stability over time [14;17]. Some authors argue that the choice of occlusal scheme has little clinical significance because most patients are able to adapt to changes [97]. Occlusal patterns also appear to have a relative role on mastication [14]. Regardless of the occlusal scheme adopted, masticatory efficiency with implant-supported restorations is considered to be very close to that of natural dentition as well as maximum masticatory strength is equally high, if not higher [99]. In contrast, occlusal patterns assume a major role in the development of functional forces that are transmitted to the supporting bone through prosthetic connections [14]. In IFCDPs, the decrease in proprioceptive feedback, combined with prosthetic stiffness, requires special attention to biomechanical factors [97]. Occlusion is not a simple contact between opposite surfaces, but includes multiple inclined planes and different force vectors. Occlusal forces are multidirectional, complex, unpredictable, transient and, often, non-intuitive [100]. Each occlusion/disocclusion cycle is characterized by transient loads that are very distant from traditional unidirectional force assumptions [100]. For these reasons, outlining truly biomechanically effective occlusal theories is very complex. Differences between teeth and implants underlie the occlusal theories applied in implant prosthetics. Some authors state that clinical success and longevity of dental implants can be achieved through biomechanically controlled occlusion [27]. The mechanically inspired occlusal scheme is aimed at reducing unfavorable occlusal forces in an attempt to prevent biomechanical complications. It envisions centralizing forces predominantly along the long axis of the implant body and minimizing horizontal forces and cuspal interference. An example of these occlusal theories is implant-protected occlusion (IPO) [101]. Currently, the lack of scientific evidence does not make it possible to define the best occlusal scheme for IFCDPs. Each case must be evaluated individually and needs individualized planning [27]. The principle of "personalized occlusion" of IFCDPs arises from the consideration of several individual factors capable of conditioning the loads on prostheses and implants: geometry, number, length, diameter, angulation and position of implants; prosthetic type and design: prosthetic material; direction and magnitude of loads; status of the antagonist arch, conformation of the jaws; bone quality; and age and sex of the patient [14,27]. Different patient conditions exert different amounts of force in terms of magnitude, duration, type and direction. Before analyzing occlusal patterns and morphology, it should be pointed out that axial loading is pure theory, and in nature, occlusal forces on teeth are non-axial, and all implant-supported restorations are subjected to non-axial loads. Although some occlusal theories consider the directionality of occlusal forces to be a critical factor, in IFCDPs the recommendation to load implants primarily axially is a questionable goal and difficult to achieve. Given that occlusal force can exert high stresses on the framework and transfer to implants and surrounding bone, in IFCDPs the framework acts as a rigid implant splint, allows the distribution of occlusal contacts within a polygon determined by the implant arrangement, and regulates the distribution of stresses from the framework to the implants and bone [102]. Contemporary treatment with high success "all-on-four" demonstrates the lack of detrimental effect of nonaxial loads: distal tilted implants show better stress distribution than vertical distal implants, which, in the presence of cantilevers, exhibit increased levels of peri-implant stress [103]. Regardless of implant placement, passive framework adaptation is a nonnegotiable prerequisite for IFCDPs: one of the factors most responsible for generating static stresses within the bone and at the peri-implant interface, in the absence of occlusal loading, is the failure of passive adaptation between the implant superstructure and the abutments [51]. However, there is no scientific evidence of a cause-and-effect link between passive framework failure and biological effects on peri-implant bone [51]. On the basis of these considerations, we propose a biomechanical risk score index dedicated to IFCDPs: the purpose is to provide the clinician with a practical and immediate tool to personalize prosthetic treatment and to allow the implementation of design expedients aimed at a favorable long-term prognosis of rehabilitation (Table 1).

Table 1. IFCDPs Personalized Risk Factors Score Index.

Risk Factors	Score
Presence of parafunction, bruxism	1
Presence of cantilever	1
Cantilever length more than 10 mm (equivalent to 1 molar)	0,5
Cantilever A-P spread unfavourable (recommended 1.5:1)	1
Lower number of implants than recommended (6-8 implants in the upper jaw and 4-8 mandibular implants)	1
Presence of narrow diameter and/or short/ultrashort implants	0,5
Implants placed in poor quality bone for heavy load bearing area	0,5
Sub-optimal passive fit of prosthetic framework	0,5
Occlusal materials susceptible to wear	0,5
Double IFCDP in antagonism	0,5
No occlusal splints in cases of parafunctions and/or bruxism	0,5
Predictive signs of biomechanical complications	
Wear of occlusal material	0,5

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Fracture, chipping of occlusal material	0,5
Loosening of abutment/prosthetic screws	0,5
Fracture of abutment/prosthetic screws	1
≤ 2: Low biomechanical risk 3-5: Moderate biomechanical risk >5: High biomechanical risk	

8. Clinical Recommendations on the Management of Occlusion in IFCDPs

In the literature, the occlusal concepts applied in IFCDPs refer to three reference schemes: mutually protected occlusion, group function and bilaterally balanced occlusion. The choice of occlusal scheme is defined according to the antagonist arch [11]. In cases of antagonistic implant rehabilitation with removable complete dentures, bilaterally balanced occlusion is indicated for better force distribution and better prosthetic stability [27]. Although studies on the subject are still scarce, there is a consensus that bilaterally balanced occlusion is also advantageous in terms of stability in cases of antagonist arches prosthesis with implant-supported overdenture prostheses [104]. Mutually protected occlusion and group function are the occlusal schemes usually employed for IFCDPs antagonistic to natural dentition or fixed prosthetic rehabilitations. The mutually protected occlusion (canine guidance) scheme implies that during lateral excursions and protrusion the posterior teeth are protected by the anterior guidance, while during centric occlusion the anterior teeth are expected to have light contact and be protected by the posterior teeth. The alternative is occlusion with group function (also called unilateral balanced occlusion). It is definitely indicated in cases where the canines of the prosthetic or antagonist arch are to be spared from excessive excursion loads. Some authors consider group function more advantageous in terms of load distribution [105]. It seems to promote patient comfort and reduce the mechanical stress of the prostheses during function [27,97]. A recent FEA study on “all-on-four” IFCDPs with different occlusal schemes, in addition to confirming higher stress values at the implant neck and peri-implant cortical bone, showed that stresses would be more advantageously distributed with group function [106]. Regardless of the occlusal scheme, the occlusion should provide bilateral stability in centric occlusion with equally distributed contacts and occlusal loads [104]. In addition, the occlusion should provide for freedom in centricity of approximately 1-1.5 mm. The concept of “Freedom in Centric” was first introduced by Schuyler in the 1960s [107]. Dawson, to express the same concept, later coined the term “long centric” [108]. An occlusion with long centricity requires the elimination of any occlusal interference between maximum intercuspation (MIP) and centric relation (CR). Freedom in centric allows the avoidance of precontact during function [109] and promotes patient comfort, especially in cases of rehabilitated edentulous patients who have lost proprioception [97]. Some studies suggest providing non-exaggerated anterior guidance: the steeper the anterior guidance, the greater the horizontal forces on prostheses and anterior implants. Occlusal forces should be distributed as evenly as possible between the incisors from the centric to the edge-to-edge position. The extent of anterior overbite in addition to anterior guidance is conditioned by the esthetic result for which a slight vertical overlap of the anterior teeth is essential [97]. Regarding occlusal morphology, occlusal strategies such as cusp inclination reduction, “shallow” occlusal anatomy, and 10-20% reduced occlusal table born to minimize lateral forces and bending moments in implant-supported partial restorations [32], in IFCDPs seem to assume less significance. In addition, the design of occlusal surfaces should consider that chewing efficiency is affected by changes in tooth size and shape [110]. Specifically, reducing occlusal surface area results in decreased efficiency of comminution of food particles per unit of masticatory work. Greater occlusal area has been correlated with increased masticatory efficiency in experimental studies [110]. In addition, the occlusal morphology of artificial teeth can influence masticatory function. A recent systematic review shows that anatomical teeth improve chewing efficiency and muscle activity in removable partial denture wearers. In contrast, nonanatomical teeth increase muscle activity, negatively affecting chewing [111]. These data suggest

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that the adoption of anatomical teeth with a not narrowed occlusal table represents a potentially more advantageous strategy than occlusal modifications that may compromise chewing efficiency and force the patient to increase chewing cycles with a counterproductive effect in terms of occlusal loads (Table 2).

Table 2. Clinical recommendations on the management of occlusion in IFCDPs.

Occlusal recommendations in IFCDPs:

- Mutually protected occlusion or group function in the case of an antagonistic arch with natural dentition or with fixed prosthodontics or implant-fixed prostheses. Bilaterally balanced occlusion if the implant prosthesis is antagonistic with a removable complete denture or overdenture
- Bilateral stability in centric occlusion
- Equally distributed contacts and occlusal loads. Simultaneous bilateral contacts on canines and posterior teeth and light contacts on incisors
- Freedom in centric 1-1.5 mm (long centric)
- Anatomical teeth and occlusal table not narrowed
- Minimal anterior overbite. Reduced anterior guidance in protrusive movements.
- In lateral movements, canine guidance or group function with less steep paths.
- Posterior cantilevers with clearance of approx. 100 µm and no contact in lateral and protrusive excursions. Cantilever extension not exceeding 12 mm in the upper jaw and 15 mm mandibular. In bruxer, short cantilevers (8 mm) and occlusal splints are recommended in selected cases.
- In cases of antagonism with a removable complete denture: during excursion movements, look for one or more balancing contacts, planning more anteroposterior space for the anterior teeth. If posterior cantilevers are present, it is advisable to leave the most distal tooth slightly out of occlusion.
- Occlusion design in definitive IFCDPs is incompatible with high-wear occlusal materials

Occlusal recommendations in immediate loading:

- Avoiding cantilevers or minimizing the length of cantilevers
- In lateral movements, group function or canine guidance with flat paths and minimal vertical overlap
- In protrusive movements, guidance distributed over all anterior teeth, including canines, with flat paths and minimal vertical overlap
- Even if the implant-supported prosthesis is antagonistic to a removable complete denture, balancing contacts should be avoided in excursion movements at the cost of making the prosthesis unstable

5. Conclusions

Biophysiological differences between teeth and dental implants and the topic of occlusal overload, although controversial, form the basis for occlusion management in IFCDPs. Occlusion management is lacking in scientific evidence: recommendations and suggestions on occlusion are mainly based on expert opinion and intuitive guidelines, lacking a high level of scientific evidence. However, it is evident how the favorable prognosis of IFCDPs is linked to the correct understanding of the biomechanical principles involved. In the design of IFCDPs, the lack of proprioceptive feedback dictates special attention to biomechanical factors: minimizing overload complications and conferring biomechanical stability are among the main goals of occlusion. Despite the lack of scientific evidence, occlusal overload can be considered a potential accelerating factor for peri-implant bone loss in the presence of plaque and inflammation. Moreover, overload is a recognized factor of mechanical complications in IFCDPs. Cantilever and bruxism represent the most critical biomechanical stressors and require personalized strategies aimed at defusing unfavorable forces. Occlusal materials with high levels of wear are incompatible with stable occlusion, proper load distribution, and masticatory efficiency. In IFCDPs, occlusion must be decided on the basis of several factors capable of conditioning the loads on prostheses and implants: each case must be evaluated individually and needs a customized occlusion. The biomechanical risk score index is configured as a useful and immediate tool to personalize prosthetic treatment, allowing the clinician to implement arrangements aimed at a favorable long-term prognosis of IFCDPs. The choice of occlusal scheme should be defined according to the antagonist arch according to criteria of advantageous load distribution.

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