Systematic Review

Occlusal Scheme Effect on the Biomechanical Response of Full-Arch Dental Prosthesis Supported by Titanium Implants: A Systematic Review

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Abstract: Dental implant-supported prosthesis are widely used in oral reconstruction of totally edentulous patients. Nonetheless, one of the most common failures in these cases is caused by overloading from improper occlusion. The aim of this work was to determine if the occlusal scheme influences the biomechanical response in implant-supported dental prostheses. Searches were conducted in several databases (PubMed/MEDLINE, The Cochrane Library, Web of Science, Scopus, LILACS, and OpenGrey). We found 632 publications and 521 studies remained after removing duplicates. After applying the inclusion criteria, five studies were used in this systematic review: one clinical trial, one retrospective clinical trial, one in vitro and two in silico. The results show the lack of clinical and laboratory studies about occlusion in implant-supported prostheses. Although there are several studies regarding implant occlusion schemes, there remains a lack of scientific evidence to support that one specific occlusal scheme is superior to another, or to help define the ideal occlusal scheme that improves the clinical outcome. It can be concluded, however, that the proper distribution of loads and the absence of occlusal interferences can increase implant longevity. Thus, more clinical and laboratory studies must be carried out to obtain an occlusal scheme that favors the clinical success of implant rehabilitation.

Keywords: dental implants; dental occlusion; occlusal scheme; biomechanical response; prosthesis failure; mouth rehabilitation

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1. Introduction

Since 1982, at the Toronto Conference on Osseointegration in Clinical Dentistry, a new possibility of treatment with edentulous patients was accepted with the proof of the effectiveness of integrated bone implants [1,2]. Thenceforth, dental implant-supported prosthesis have been extensively used for oral reconstruction of partial and complete edentulism. However, even with high success rates, late implant failures are mainly caused by peri-implantitis and occlusal overloading, resulting from improper occlusion [3–5]. Overloading creates stress around the implant components and bone–implant interface that is not biologically acceptable [5]. Dental implants frequently suffer from occlusal overload because the prostheses lack the supporting periodontal ligaments that are known

to provide the shock-absorbing function of natural teeth [6]. Occlusal overload can cause mechanical complications, such as screw loosening and fractures, both in the prosthesis and in the implant itself, eventually compromising the longevity of the treatment [7]. The scientific literature has reported that the clinical success and longevity of dental implants can be achieved by biomechanically controlled occlusion [6,8]. It is important for all clinicians to know how occlusal force (normal or excessive), may influence implant successful rates. The ideal implant occlusion would allow controlled stress around the implant components, provide a prosthetic and biological acceptable bone–implant interface and obtain long-term stability of the marginal bone and prosthesis [9]. Studies that cite balanced occlusion concepts and recommendations are generally from natural dentition or conventional complete dentures. Few articles are found in the literature discussing ideal occlusion in implants, especially with total rehabilitation [10,11]. There is a lack of studies in the literature that provided theories or protocols on implant occlusion, few of them provided strong evidence about occlusion stability for dental implant. Thereby, the aim of this systematic review was to determine, even with the limitations in the literature, if the occlusal scheme influences the biomechanical response in full implant-supported prostheses.

2. Materials and Methods

2.1. Protocol Registration

This review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) 2020 guidelines [12] and registered at the International Prospective Register of Systematic Reviews—University of York (PROSPERO) ID: CRD42021249350.

2.2. Focus Question

The focus question PICO was: Does the occlusal scheme influence the biomechanical response in dental prosthesis implant-supported? (The question was as broad as possible to reach the largest number of articles). It was formulated considering the following four elements:

- Population (patients)—Dental implants/dental prosthesis, implant supported/edentulous mouth;
- Intervention—occlusal scheme/dental occlusion/Implant-protected occlusion/occlusal stability;
- Comparison—none;
- Outcome—dental stress distribution/ mouth rehabilitation.

2.3. Literature Search

The review was carried out from March to August 2021 (respecting the monthly alerts received with the update of newly published articles). Electronic searches were performed in the following databases: PubMed/MEDLINE, The Cochrane Library, Web of Science, Scopus, LILACS, and Opengrey. The research covered the languages English, Spanish and Portuguese, and had no restrictions regarding the period of publication or type of article.

The search used the Medical Subject Headings (MeSH) terms with several combinations and adapted according to each database specification. The search strategy is shown in Table 1. The condition (disease or healthcare) studied was focused on occlusal schemes and biomechanical response on dental implant prosthesis, in agreement with the following inclusion and exclusion criteria:

- Inclusion: Dental rehabilitation with titanium implant, Implant-protected occlusion, edentulous mouth, full-arch rehabilitation.
- Exclusion: Rehabilitation without dental implant. Single implant rehabilitation.

Table 1. Algorithms for electronic searches in databases.

PubMed = 512 *
P = ((((((“Dental implants”[MeSH Terms]) OR (“Dental implants”[Title/ Abstract])) OR (“Dental Implant”[Title/ Abstract])) OR (Surgical Dental Prostheses[Title/ Abstract])) OR (Edentulous Mouth[MeSH Terms])) OR (Edentulous Mouth[Title/ Abstract]))   AND   I = (((((((“Dental occlusion”[MeSH Terms]) OR (“Dental occlusion”[Title/ Abstract])) OR (“Occlusion, Dental”[Title/ Abstract])) OR (“Canine Guidance”[Title/ Abstract])) OR (“Occlusal Guidance”[Title/ Abstract])) OR (“Occlusal Plane”[Title/ Abstract])) OR (“Occlusal scheme”[Title/ Abstract])) OR (Implant-protected occlusion[Title/ Abstract])) OR (“Occlusal stability”[Title/ Abstract]))   AND   O = ((((((“Dental stress analysis”[MeSH Terms]) OR (Dental stress distribution [Title/ Abstract])) OR (“Prosthesis Failure”[MeSH Terms])) OR (“Mouth rehabilitation”[MeSH Terms])) OR (rehabilitations, mouth [Title/ Abstract]))
Scopus = 111
TITLE-ABS-KEY (“Dental implants” OR “Dental Implant” OR “Surgical Dental Prostheses” OR “Edentulous Mouth”))   AND   (TITLE-ABS-KEY (“Dental occlusion” OR “Occlusion, Dental” OR “Canine Guidance” OR “Occlusal Guidance” OR “Occlusal Plane” OR “Occlusal scheme” OR “Implant-protected occlusion” OR “Occlusal stability”))   AND   (TITLE-ABS-KEY (“Dental stress analysis” OR “Dental stress distribution” OR “Prosthesis Failure” OR “Mouth rehabilitation” OR “rehabilitations, mouth”))
Web of Science = 3
TS = (“Dental implants” OR “Dental implants” OR “Dental Implant” OR “Surgical Dental Prostheses” OR “Edentulous Mouth” OR “Edentulous Mouth”)   AND   TS = (“Dental occlusion” OR “Occlusion, Dental” OR “Canine Guidance” OR “Occlusal Guidance” OR “Occlusal Plane” OR “Occlusal scheme” OR “Implant-protected occlusion” OR “Occlusal stability”)   AND   TS = (“Dental stress analysis” OR “Dental stress distribution” OR “Prosthesis Failure” OR “Mouth rehabilitation” OR “rehabilitations, mouth”)
Cochrane Library = 6
#1 MeSH descriptor: [Dental Implants] explode all trees 1481   #2 (“Dental implants” OR “Dental implant” OR “Surgical Dental Prostheses”):ti,ab,kw   #3 #1 OR #2   #4 MeSH descriptor: [Mouth, Edentulous] explode all trees   #5 (“Edentulous Mouth”):ti,ab,kw   #6 #4 OR #5   #7 #3 OR #6   #8 MeSH descriptor: [Dental Occlusion] explode all trees   #9 (“Dental occlusion” OR “Canine Guidance” OR “Occlusal Guidance” OR “Occlusal Plane” OR “Occlusal scheme” OR “Implant-protected occlusion” OR “Occlusal stability”):ti,ab,kw   #10 #8 OR #9   #11 MeSH descriptor: [Dental Stress Analysis] explode all trees   #12 (“Dental stress distribution”):ti,ab,kw   #13 #11 OR #12   #14 MeSH descriptor: [Prosthesis Failure] explode all trees   #15 MeSH descriptor: [Mouth Rehabilitation] explode all trees   #16 (“rehabilitations, mouth”):ti,ab,kw 0   #17 #15 OR #16   #18 #13 OR #14 OR #17   #19 #7 AND #10 AND #18

Table 1. Cont.

Lilacs = 0
(MH: “Dental implants” OR “Dental implants” OR “Implantes Dentários” OR “Implantes Dentales” OR “dental implant” OR “Implante dentário” OR “Implante Dental” OR “Surgical Dental Prostheses” OR “Prótese Dentária Cirúrgica” OR “Prótesis Dental Quirúrgica” OR MH: “Edentulous Mouth” OR “Edentulous Mouth” OR “Boca Edêntula” OR “Boca Edêntula”) AND (MH: “Dental occlusion” OR “Dental occlusion” OR “Oclusão Dentária” OR “Oclusión Dental” OR “Canine Guidance” OR “Orientação de Canino” OR “Orientación Canina” OR “Occlusal Guidance” OR “Orientação Oclusal” OR “Orientación Oclusal” OR “Occlusal Plane” OR “Plano Oclusal” OR “Occlusal scheme” OR “Esquema oclusal” OR “Occlusal stability” OR “Estabilidade oclusal” OR “Estabilidad oclusal” OR “Implant-protected occlusion” OR “Oclusão protegida por implante” OR “Oclusión protegida por implantes”) AND (MH: “Dental stress analysis” OR “Dental stress distribution” OR “Distribuição de estresse dentário” OR “Distribución del estrés dental” OR MH: “Prosthesis Failure” OR MH: “Mouth rehabilitation” OR “Rehabilitations, mouth” OR “Reabilitações, boca” OR “Rehabilitaciones, boca”)
Open Grey = 0

* Article numbers found in each database.

All articles were analyzed by two independent reviewers (GLCL, PFZ), based on the pre-established criteria by this review (following the PICO question). The reviewers loaded the articles in Mendeley reference editor (version 1.19.8, Mendeley Ltd., Amsterdam, The Netherlands) removing the duplicates. The titles and abstracts were selected for inclusion, and after that, full-text reading assessed eligibility. In case of disagreement between the reviewers, discussions were held to establish an inclusion or exclusion agreement for the study in question. In this systematic review the K Cohen test has been performed for the accuracy and reliability. Both operators that selected the articles followed the review protocols and guidelines. The % of agreement between the authors was calculated in 97.2% with a Cohen’s K coefficient equal 0.43.

The in vitro and finite element analysis studies were included because they complemented the occlusion analysis in different methodologies, enabling a better understanding of the biomechanical response, correlating with the clinical studies included in this systematic review.

2.4. Quality Assessment of Risk of Bias

The risk of bias of the included studies was assessed using the Cochrane collaboration’ tool. The assessment was analyzed according to seven established criteria that the article must have in their studies (according to each article type) and classified in three levels: The high risk was considered when only two criteria were included, the middle risk until 3 and 4 criteria were included, and low risk when 5, 6 or 7 criteria were included.

3. Results

The electronic search identified 632 publications, and after removing the duplicates, 521 studies remained. Applying the inclusion criteria, 32 papers were selected with potentially relevant, and six of them were selected. However, one article [13] was excluded because it was not possible to access the full text, so five studies [14–18] were used in this systematic review, corresponding to one clinical trial, one retrospective clinical trial, one in vitro and two in silico (finite element analysis—FEA). The meta-analysis evaluation and the “Assessment of Risk of Bias” were not conducted because of the heterogeneity of the included studies. The PRISMA flowchart for this systematic review is depicted in Figure 1. A table of specific characteristics was made for clinical trials studies (Table 2), and a general table for all included studies, divided into part A and part B (Table 3).

Figure 1. PRISMA flowchart.

Table 2. Clinical trials studies' specific characteristics ($n = 2$ articles).

First Author (Year) [Reference]	n	Patients Characteristics	Observation Time	Type of Analysis	Ethical Comite
Linkevicius et al. (2008) [15]	251-(21)	Male and Female with the average age of 42.1 ± 11.3 years (range from 19 to 76 years old)	1–48 months	Clinical inspection—Ceramic failure	All the patients included into the study gave informed content to use
Falk et al. (1990) [14]	8	Six men and two women participated in this study. Their mean age was 56 years (range 43 to 65)	Immediately evaluation	Force recording. Mingograf jet recorder (Elema Schnander, Solna, Sweden) via a 9-V battery-powered bridge amplifier. The occlusal forces were then measured according to a standardized test program.	Ethical disclosure not mentioned. Patients from Department of Prosthodontics at The Institute for Postgraduate Dental Education, Jnkping, Sweden.

Table 3. General characteristics of included studies ($n = 5$ articles).

Part A							
First Author (Year) [Reference]	Country	Study Type	Purpose of Study	Analyzed Groups	Analyzed Occlusion	Test Type	Results
Greco et al. (2010) [17]	Brazil	FEA	Compared the stresses generated by the disocclusion in the canine guide occlusion (CGO) and bilateral balanced occlusion (BBO) on the implants and metallic infrastructure of a modified Brnemark protocol	(1) Nodal load of 15 N with an angle of 45° to the canine tooth—CGO (2) Nodal load of 15 N with a angle of 45° distributed across three teeth—BBO	Not mentioned	Linear elastic static analysis (maximum stress)	The disocclusion in BBO induced lower tensions than those in CGO in a mandibular complete denture supported by implants without free distal ends
Trker et al. (2019) [13]	Turkey and USA	FEA	Evaluate stress distributions on implants and alveolar bone due to occlusal load produced during chewing by prostheses prepared according to the All-on-Four concept with different occlusal schemes	(1) CGO: occlusal scheme prepared according to canine-guided occlusion (2) GFO: occlusal scheme prepared according to group function occlusion (3) BBO: occlusal scheme prepared according to bilateral balanced occlusion (4) LO: occlusal scheme prepared according to lingualized occlusion (5) MO: occlusal scheme prepared according to monoplane occlusion	Maximum intercuspation (450 N) Lateral movement (93 N to CGO; 200 N to GFO; 400 N to BBO, LO and MO) Protrusive movement (94 N to CGO and CFO; 400 N to BBO, LO and MO)	Stress outputs for the maxilla and mandible were taken as maximum principal stress (Pmax) and minimum principal stress (Pmin). Von Mises stress values were obtained for the implants	The highest stress values on alveolar bone occurred around the neck region of the implants in cortical bone, and the highest stress values on implants occurred at the neck region of the implants The highest stress values were observed in maximum intercuspation with monoplane occlusion, during protrusive movement with BBO, and during lateral movement with bilateral balanced and monoplane occlusion The lowest stress values were observed with canine-guided occlusion in all conditions and on all structures

Table 3. Cont.

Part A							
First Author (Year) [Reference]	Country	Study Type	Purpose of Study	Analyzed Groups	Analyzed Occlusion	Test Type	Results
Block et al. (2017) [16]	Israel	In vitro	Investigate the effect of implant insertion on the strain levels in bovine bone and to evaluate the effect of simulated mastication cycles on the strain levels around implants, in splinted and nonsplinted restorations with different occlusal schemes.	Full splint (FS) loading: complete cross-arch splint force on entire metal plate. Segmented cross-arch splint (SS) loading: metal plate cut in the midline and force applied on the entire metal plate. 3. Canine loading (CL): disconnecting right canine from distal teeth while maintaining proximal contact with adjacent premolar. Metal plate also cut accordingly. Load applied on tooth 6. Premolar loading: Premolar loading (PL): splinted group function restoration in same configuration as in CL (teeth 4 and 3 connected). Load applied on teeth 5 and 4. Premolar-segmented loading (PSL): nonsplinted group function disconnecting second premolar from first molar while maintaining proximal contacts with adjacent teeth. Metal plate also cut accordingly. Load applied on teeth 5 and 4. Single implant loading (SL): loading of first molars full separation of tooth 3 from adjacent teeth. Load applied only on tooth 3.	Canine guidance, and group function configurations.	The restoration was loaded by an Instron machine (model 4502; Instron Corp., Buckinghamshire, United Kingdom) with a force amplitude of 135 N at a sinus of 1 Hz for 300 cycles, simulating 5 min of mastication. Strain was measured during loading, and residual strain measurements were recorded after loading stopped	Comparing the 3 different guidance configurations, PL presented the most favorable strain results both in loading, showing the best distribution of vertical compared with horizontal strain, and in residual strain with the lowest horizontal strain values ($p < 0.05$). The least favorable strain results were in CL where there were the highest levels of horizontal strain in loading and even higher levels of horizontal residual strain ($p < 0.05$). Premolar loading guidance presented the most favorable loading and residual strain results ($p < 0.05$).

Table 3. Cont.

Part A							
First Author (Year) [Reference]	Country	Study Type	Purpose of Study	Analyzed Groups	Analyzed Occlusion	Test Type	Results
Linkevicius et al. (2008) [15]	Lithuania	Clinical Trials	Define the fracture rate of implant supported metal-ceramic restorations delivered in private practice, and to identify if a restoration's contact during eccentric mandible movements has any influence on ceramic fracture rates	A regular occlusal scheme was applied. Habitual occlusal position, occlusal contacts were not positioned on oblique planes and posterior prostheses did not have contact during eccentric mandible movements 3 types of rehabilitations: - single crowns - fixed partial dentures - full cross-arch reconstructions 4 follow up time groups: - 1 year - 1–2 years - 2–3 years - Over 3 years	Eccentric mandibular movements	Clinical Inspected for the presence of mechanical complications, namely ceramic fractures. They were distinguished as: adhesive co-adhesive	Full-arch metal-ceramic restorations experienced 38.1% chipping. The majority of the failures in the current study were of co-adhesive kind. The difference between the full-arch restorations and single or partial fixed crown groups was found to be statistically significant. It was concluded that 54.2% of all failures occurred in guiding restorations. Consequently, contact during eccentric mandibular movements significantly increases the possibility of veneer complication
Falk et al. (1990) [14]	Sweden	Clinical Trials	The aim of this study was to determine whether a small, experimentally introduced, premature occlusal contact on the distal cantilever unit in dentitions with fixture-supported prostheses occluding with complete dentures would further amplify the unfavorable distribution of axially directed occlusal forces	Basic occlusion with simultaneous occlusal contacts in habitual occlusion interfered occlusion in habitual occlusion. Basic occlusion in preferred chewing side. Interfered occlusion with a 100-µm-high premature occlusal contact on the second cantilever unit of the preferred chewing side.	Closing forces in habitual occlusion and chewing movements and preferred and non-preferred side.	Local and total maximal closing forces in habitual occlusion. Mean local and total chewing forces calculated from one randomly selected chewing sequence. For force recording, the transducers were connected to a Mingograf jet recorder (Elema Schönander, Solna, Sweden) via a 9-V battery-powered bridge amplifier. The occlusal forces were then measured according to a standardized test program.	The premature occlusal contact of the preferred chewing side had no influence on the total maximal closing forces as compared to basic occlusion. The group mean local closing force at the interfered was significantly increased ($p < 0.05$). The interfered occlusion resulted in a slight, although nonsignificant, increase of the vertical bending stress during closing but had no effect on the chewing vertical bending stress

Table 3. Cont.

Part B					
First Author (Year) [Reference]	Region of Study	Number of Implants	Feature of the Implants	Materials Type	Antagonist Type
Greco et al. (2010) [17]	A model simulat- ing a jaw	5 installed between the mental foramen, with a distance of 4 mm between their platforms and 2 located at the midpoint of the occlusal surface of the first molar	All implants were cylindrical. The dimension of 13 mm in height and 3.75 mm in diameter is about the 5 implants in anterior area; 5 mm in height and 5 mm in diameter is about the 2 implantes in posterior area	Implants anterior area: (Brånemark System® Mk III Groovy; Nobel® Biocare, Zürich-Flughafen, Switzerland); Posterior area: (Titamax WS®; Neodent®, Curitiba, PR, Brazil) Prosthetic components made of titanium were 3 mm in height (Multi-unit Abutment®; Nobel Biocare®) A nickel-chromium infrastructure (Wiron® BEGO, Goldschlangerar, Bremen, Germany) with a thickness of 6 mm, a height of 4 mm and a total length of 112 mm with free distal ends 12 dental elements in acrylic resin with a range of 2 mm of gingival	Not applicable
Türker et al. (2019) [13]	Human maxilla and jaw	4 implants in maxilla: distance from the midline to the anterior implant in the was 15.4 mm, the distance between the two implants was 30.8 mm, and the distance between the anterior and posterior implants was 31 mm 4 implants in jaw: the distance from the midline to the anterior implant was 14.2 mm, the distance between the anterior two implants was 28.4 mm, and the distance between the anterior and posterior implants was 30.2 mm	The implants were internal hexagon type. Distal sloping of posterior region implants was performed at 40° for both the maxilla and mandible Dimension of 4 × 10 mm² for the anterior region and 4 × 13 mm² for the posterior region	Implants: OsseoSpeed tx 4.0 S Astra Tech; Dentsply Sirona, York, PA Flat abutment for the anterior region (20° UniAbutment 3.5/4.0; Astra Tech), and angulated abutment (Angled Abutment 3.5/4.0; Astra Tech) The bar structure in the maxilla was 5 mm wide, 3 mm high, and 95.8 mm long. The bar structure in the mandible was 94.8 mm long, and despite variation in different regions, it was 5 mm wide and 3 mm long on average (not mentioned the material) Teeth with sim- ilar crown sizes and crown widths were chosen for all occlusal concepts (Ivostar; Ivoclar Vivadent)	All-on-Four protocols
Block et al. (2017) [16]	Bovine jaw and maxil- lary teeth was set up	8 Implants, teeth location numbers: 2, 3, 4, 6, and 11, 13, 14, 15 (position of canines, second premolars, first and second molars).	Not mentioned	Titanium-alloy abutments were connected to the implant analogs.(SPI;Alpha-BioTec, Petah-Tiqwa, Israel). A full-arch cast metal restoration were placed on the abutments. This restoration consisted of a metal framework with 5 dental units on each side of the arch.	Not applicable
Linkevicius et al. (2008) [15]	Maxillary and jaw	Not mentioned	Not mentioned	Titanium implants (BioHorizons, Ala, USA) Metal- ceramic. frameworks alloy Co-Cr was used as base metal. Different ceramics were used for layering in fabrication of protheses GC Initial (GC, Japan), Inspiration (Heimerle-Meule, Germany) Design (Ivoclar, Liechtenstein) Vita VM7 (Vita Zahnfabrik, Germany)	Full arch rehabilitation

Table 3. Cont.

Part B					
First Author (Year) [Reference]	Region of Study	Number of Implants	Feature of the Implants	Materials Type	Antagonist Type
Falk et al. (1990) [14]	Anterior region of the jaw, between the mental foramina	5 or 6 titanium implants	The shape of the cantilever joints was roughly elliptic, and the dimensions of the joints as well as the whole metal framework of the construction were approximately 5 mm high and 4 mm wide. The yield strength for hardened type III gold alloy is approximately 440 N/mm ² , and for unhardened it is approximately 310 N/mm ²	Titanium fixtures. The metal frameworks were cast in type III dental gold alloy	Complete dentures

Quality Assessment of Risk of Bias

A high level of bias was evident in one publication included in this review, a low level of bias was evident in two publications included in this review and two publications were considered to have a medium risk of bias. Table 4 shows the quality assessment of the studies and the risk of bias.

Table 4. Quality assessment of the included studies. Red is high level of bias, yellow is middle risk of bias, green is low risk of bias and blue is unclear data. Not applicable scores (N/A) was also used due to the heterogeneity of data.

	Sample Calculation or Numerical Model Validation	Sample Randomization	The Number (n) of Specimens/ Patients Is Clear	Parameters for Clinical Analysis Standardized or Boundary Conditions with Proper References	Ethical Committee	Blind Analysis	Parameters for the Mechanical Test	Overall Risk of Bias
Linkevicius et al. (2008) [15]							N/A	
Falk et al. (1990) [14]							N/A	
Block et al. (2017) [16]		N/A			N/A	N/A		
Greco et al. (2010) [17]		N/A			N/A	N/A		
Türker et al. (2019) [13]		N/A			N/A	N/A		

4. Discussion

The aim of this systematic review was to identify which would be the best occlusal scheme to be used in a complete arch rehabilitation of implant-supported prosthesis. In this search, it was possible to perceive the lack of studies aimed at answering the question proposed in this review. This is a common doubt among prosthetists when it is said about occlusion in implant-supported prostheses, since there is a complexity in planning to get a better distribution of masticatory load between the structures involved [11].

One of the most important criteria for implant success is occlusion, and the implant-supported dentures combine concepts of conventional total dentures and fixed implant-supported dentures [17,19]. Implant protected occlusion is an occlusal plan which was designed to provide an improved longevity of both implant and the prosthesis, it was described for the first time by Misch and Bidez [20]. That provides the maximum intercuspation during clenching force and reduces occlusal load on implant, which helps in protecting the implant. For a stable occlusion it is important to avoid overloading the dental implants and the bone, that can lead to biological and mechanical complications. Consequences of biomechanical overloads are early implant failure, early crestal bone lost, intermediate to late implant failure screw loosening, uncemented restoration, component failure, porcelain fracture, prosthesis fracture and peri-implant disease [21,22]. Misch and Bidez identified the factors that can affect the implant protected occlusion, which are as follows: no premature occlusal contacts or interferences (timing of occlusal contacts), influence of surface area, mutually protected articulation, implant body angle to occlusal load, cusp angle of crown (cuspal inclination), cantilever or offset distance, occlusal contact position, implant crown contour, protection of the weakest components, occlusal materials [20]. The influence of crown height is still controversial in literature [20,23].

In addition, a randomized controlled trial demonstrates that implant-supported fixed dental prostheses may require a higher prosthetic maintenance for replacing worn-out components, which in the long term might make this treatment option more expensive than it appears [24]. For that reason, the occlusion planning and further adjustments are necessary to improve the treatment longevity [24].

Regarding the occlusal scheme, the studies are still trying to develop the ideal occlusion pattern for dental implant rehabilitation. According to the articles included in this review, Block et al. concluded that premolar loading guidance presented the most favorable loading and residual strain results, and the least favorable strain results were in canine loading where there were the highest levels of horizontal strain in loading and even higher levels of horizontal residual strain [16]. The authors explained that the possible reason for that finds is the fact that in canine guidance the loaded canine was in contact only distally, referring forces in one direction in a way that the strain grew distally compared with premolar-segmented loading configuration where the loaded premolars were in contact mesially and distally, referring forces in two directions. This was corroborated by the study of Wie [25] which evaluated 56 patients with different occlusal schemes for dental implants and concluded that group function occlusion was the preferred contact pattern, followed by canine guidance and balanced articulation.

Among the *in silico* studies, Greco et al. [17] compared canine guide occlusion (CGO) with bilateral balanced occlusion (BBO) patterns on a modified Branemark-type total protocol model (without bilateral free extremity). CGO is normally the occlusal pattern expected in natural dentition, so it is also applied in cases of fixed dentures or during orthodontic treatment [26]. In cases of removable complete dentures, BBO is applied to get a better stability of the denture since the distribution of the applied force will be better distributed between the teeth [17]. The stress distribution analyzes showed a higher stress concentration in the CGO than in the BBO. The authors explain that the fact that this happened is because the BBO has three points of contact, and the CGO has only one completely focused on the canine on the working side. This finding corroborates the results of the *in vitro* study included in this review. The authors also suggest that the use of the “all-on-four”, a simplified system where the prosthesis is placed on

four implant abutments, would perhaps cancel out the tensions generated in the intermediate implants as used in this study, and would achieve an anchorage with better biological and economic advantages. Another finding is that wider implants absorb stress more than longer implants, as the most important area to look at is around the neck of the implant, where bone loss can occur.

In another *in silico* study, Turker et al. [18] evaluated the stress distribution in the alveolar bone and implants in different models of prosthesis using the “all-on-four” protocol. Five different occlusal schemes were tested—CGO, group functional occlusion, BBO, lingualized occlusion and monoplane occlusal scheme—in three types of contact: maximum intercuspation, lateral and protrusive movement. The findings showed that the highest stress values occur around the implants in the cortical bone and in the neck region of the implant, corroborating other already mentioned studies. Furthermore, the results showed that the posterior region had higher stress concentration values. The authors suggest that this may have happened because the posterior implants are located right in the center of the chewing area, and state that when planning cases, the quality of the bone and the choice of implants for this area should be prioritized. Regarding the tested occlusal schemes, the CGO presented the lowest stress values in all analyzed conditions. The authors report that this must have occurred because anterior and posterior disocclusion occurs in these cases, and oblique loads are avoided on all other teeth. They also state that in a natural condition, canine teeth, as they have long and wide roots, tolerate these loads, conduit in a condition of prosthesis over implant, further experimental studies should be carried out to support this statement.

Falk et al. [14] simulated in a clinical trial an interfered occlusion in implant supported prosthesis with a 100- μ m-high premature occlusal contact on the second cantilever unit of the preferred chewing side and in habitual occlusion. They concluded that the premature occlusal contact of the preferred chewing side had no influence on the total maximal closing forces as compared to basic occlusion and the interfered occlusion resulted in a slight, but nonsignificant, increase of the vertical bending stress. The authors justify that these facts could be explained by a premature simulated contact might have been too small, considering that there was a complete denture in the opposite jaw compensating for the supracontact with deflecting movements. They also suggest that their findings should be interpreted with caution because premature occlusal contacts have been shown to have a negative influence on the chewing pattern and the masticatory muscle activities, with a consequent risk of development of muscular and temporomandibular joint disorders or leading to increase of fatigue and occlusal overload [14].

In another article included in this review, Linkevicius et al. [15] in their retrospective clinical trial, found that restoration contact during eccentric excursions may significantly increase fracture rates. They discussed that it has been suggested that non-axial loads may be harmful to implant-supported prostheses and should be avoided whenever possible. This study finds evidence that contact during eccentric mandibular movements significantly increases the possibility of veneer complications such as chipping or ceramic fracture. These findings were corroborated the study of Chaichanasiri et al. [27] which concluded in a finite element analysis that the influence of premature contacts in dental implants is very high and a premature contact height of an implant-retained crown over 100 μ m should be avoided as much as possible to ensure the longevity of dental implants.

The results of this systematic review brought to light the lack of clinical and laboratory studies about occlusion in implant-supported prostheses, especially on implant-protected occlusion, a term which was proposed by Misch and Bidez [20] more than two decades ago, highlighting the importance of the proper distribution of occlusal loads in order to increase the survival of the implants, and consequently, their clinical success. Another important factor that was not considered much in the studies included in this review is the antagonist, since the relationship between the maxilla and the mandible will probably influence the choice of the appropriate occlusal scheme, as the equalization of forces is extremely important to achieve success long-term [11].

Despite being interesting, the results by the included FEA studies should be interpreted with care. This numerical method is a computer simulation and does not consider the complex biological and physiological adaptation of the bone around dental implant over time as well as its responses to cyclic occlusal loading [28]. This major limitation of FEA in simulating a follow-up period, considering the bone modelling and the remodeling processes demonstrates that more clinical trials are still necessary about the occlusion topic [28]. In addition, the anisotropic behavior of the bone is another limitation that the selected articles do not consider and this certainly affects the biomechanical response.

The results found in this systematic review also have some limitations due to the heterogeneity of the included studies (clinical prospective, clinical retrospective, in vitro, in silico). Therefore, due the lack of scientific evidence, it is not yet possible to define the best occlusal scheme for the rehabilitation of implant-supported prostheses. However it is clear that the proper distribution of loads and the absence of occlusal interferences can increase the longevity of implants. Thus, more studies are needed to better understand the biomechanical response, since there are several variables involved, such as the number of implants [29], dimensions and positions of the implants, type of support bone, material used in making the prosthesis [30,31], and the antagonist.

5. Conclusions

Because of the lack of scientific evidence, it is not possible at this time to define the best occlusal scheme to be used in implant-supported complete dentures. However, there is a consensus that a proper planning for each case, with adequate distribution of loads and the absence of occlusal interferences, can increase the longevity of implant-supported rehabilitations.

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