THE ASSOCIATION BETWEEN OCCLUSION AND PERI-IMPLANT CONDITION AROUND SINGLE-UNIT DENTAL IMPLANTS

A Thesis

by

CARMEN VILLASANTE GRAVES

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Chair of Committee,	Ibtisam Al-Hashimi
Co-Chair of Committee,	Jeffrey A. Rossmann
Committee Members,	Celeste Abraham Jorge A. Gonzalez David Kerns Elias D. Kontogiorgos
Head of Department,	Larry L. Bellinger

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ABSTRACT

Background: There is controversy in regards to whether occlusion plays a role in the peri-implant condition. The aim of this study was to evaluate the association between occlusion and peri-implant condition around single-unit dental implants. Materials and Methods: This cross-sectional study was conducted at the Graduate Periodontics Department of Texas A&M University BCD. Patients that had received at least one dental implant which was restored with a single-unit crown and had been in function for at least 1 year were included. The type of occlusal contact during maximal intercuspidation (MI) as well as the presence of excursive contacts on the implant during working (W), balancing (B), and protrusive (Pr) movements were recorded. Additionally, a digital sensor (T-Scan®) was used to quantify the implant relative Maximum Bite Force (rMBF) and the implant disclussion time during W, B, and Pr. Implant mobility, suppuration, pain upon vertical percussion, BOP, PD and radiographic bone loss were evaluated. Results: Forty-four patients (74 implants) participated in the study. The type of occlusal contact during MI was "heavy" in 29 implants (39%), "light" in 40 implants (54%), and 5 implants (7%) present with "no contact." Twenty implants presented with excursive contacts on the working site, whereas 4 and 7 implants presented with balancing and protrusive contacts, respectively. The mean rMBF on the implant was 10% (±9.57). The mean implant disclussion time in the working side was 1.06 sec (±0.94), whereas it was 0.58 sec (±0.66) and 0.42 (±0.59) sec for balancing and protrusive, respectively. The mean implant deepest PD was 3.66 mm (±1.17 mm). The mean radiographic bone loss was -0.18 mm (±0.83

mm). Three implants were classified as presenting with “peri-implantitis,” whereas 24 implants presented with “peri-mucositis.” None of the occlusion variables showed a statistically significant association with any of the peri-implant condition variables ($p>0.05$) Conclusion: Within the limitations of the present study, it is concluded that in a properly restored sample, occlusion in single-unit dental implants does not demonstrate an association with the peri-implant condition.

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1. INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Dental implants have become a frequent treatment approach and they have revolutionized dentistry in the last few decades [1]. Dental implants have high survival and success rates but they are not immune to complications [2]. It is important to identify factors that can play a role in the initiation and the progression of peri-implant condition deterioration.

Dental occlusion plays a central role in clinical dentistry and is essential for normal physiologic function [3]. Excessive occlusal load has been suggested as one of the potential challenges for the success of implants, their components and the prostheses.

Excessive occlusal forces in natural teeth may be manifested by mobile teeth, wear facets or myofascial pain dysfunction. In the natural dentition, the tooth responds to overload by adaptation. This adaptive process involves bone loss in the walls of the socket; the periodontal ligament space widens and the tooth becomes mobile. This can be viewed as the tooth’s attempt to move away from traumatic forces. If the traumatic force is controlled or removed, the situation will reverse itself, and the tooth will once again become firm. In the case of a dental implant in which no periodontal ligament exists, no such adaptive response is possible. When an overload situation develops, an irreversible failure of the implant or the prosthesis supported by the implant may occur. Prosthetic failures can be repaired, but may reoccur if the cause of overloading is not corrected. In the worst-case scenario, it is theorized that the overloading force may be transmitted to the bone-implant interface, causing a loss of osseointegration along with the loosening and eventual loss of the implant [4].

In a recent literature review conducted by Naert et al [5] that evaluated the biological consequences that occlusal overload may play on already osseointegrated oral implants , he concluded that “the effect of implant overload on bone/implant loss on clinically well-integrated implants is poorly reported and provides little unbiased evidence to support a cause-and-effect relationship between occlusal stress and peri-implant bone loss”.

Any study of the effect of occlusal overload and/or occlusal discrepancies in peri-implant tissue is complex. In the animal , “overload”, defined as supra-occlusal contacts on a non-inflamed peri-implant environment, did not negatively affect osseointegration and even led to a building-up tissue response [6]. In contrast, supra-occlusal contacts on inflamed conditions significantly increased the plaque-induced bone resorption around dental implants [5].

At the clinical level in humans, one of the very few studies that provides some information about the effect of maximum bite force on marginal bone loss around implants was conducted by Jofre in 2010 [7]. This study looked at mini implants that were supporting a mandibular overdenture. His results showed that there was no relationship between the maximum bite force and the marginal bone loss on the mini-implants. However, this study only included patients wearing overdentures, in which much of the support came from the mucosa, while implants act to enhance retention rather than support. Even though Jofre’s study is a randomized clinical trial, it does not have enough statistical power to conclude that there is no association between the maximum bite force and marginal bone loss around implants.

It is important to conduct human clinical studies related to this topic. However, there are intrinsic limitations when studying the effect of occlusal overload/discrepancies on the peri-implant tissue. Allocating patients into two groups that would receive randomly induced overload is not ethical. Thus, cross sectional and descriptive studies appear to be the most effective methods to evaluate the possible effects that occlusal overload and occlusal discrepancies might have on dental implants in a clinical level. The aim of the present study was to evaluate the association between occlusion and the peri-implant condition around single unit dental implants.

1.2 Literature Review

1.2.1 Occlusion in natural teeth

Harrel and Nunn [8] studied the effect of occlusal discrepancies on natural teeth and its effect on periodontitis. They used the records from a periodontics office to search for patients that underwent a complete periodontal evaluation, including occlusal analysis and had periodontal and occlusal evaluations completed at least 1 year following the initial examination. The patients were divided in three groups: untreated patients that did not receive any treatment, a partially treated group where the patients only underwent non-surgical therapy, and completed treatment group where the patients completed all recommended periodontal therapy including surgical treatment if recommended. In their results, they found that the teeth that presented with initial occlusal discrepancies had deeper initial probing depths, worse prognosis and worse mobility than those teeth without initial occlusal discrepancies. They also found that the correction of occlusal discrepancies contributed to a diminution or slowing of periodontal degeneration.

1.2.2 Occlusion in dental implants

Misch [9] has published numerous articles and book chapters about occlusion on dental implants. He uses the term “implant-protected occlusion” to refer to an occlusal schema that is designed for the restoration of endosteal dental implants, and provides improved clinical longevity of the implant and the prosthesis. Some of the factors to consider on implant-protected occlusion are listed below:

- A natural tooth has the periodontal ligament, which serves as a viscoelastic “shock absorber” decreasing the magnitude of force and stress applied to the bone. When "trauma from occlusion" occurs in natural teeth, the tooth will respond by increasing its mobility [10]. This increase of mobility will serve to dissipate the stress and strains otherwise imposed on the bone interface. A dental implants lacks a periodontal ligament, thus the load is applied directly to the surrounding bone. It is worth noting that, it has also been reported that a dental implant can also express mobility when subjected to excessive occlusal forces [11].

- Implant and tooth movement are not similar. A tooth can move 28 µm in an apical direction with an axial load. An implant under a similar load moves approximately 5 µm. For this reason, an implant supported restoration that is surrounded by teeth must be adjusted. To achieve this, the following protocol is recommended:
  1) Biting in centric occlusion with light force utilizing a thin articulating paper (less than 25 µm) is used first to assess the occlusal contacts. The implant crown will be relieved, placing heavier forces on the contiguous teeth.
  2) A stronger bite force is then applied into the articulating paper creating contact regions on both the implant restoration and the adjacent teeth. "The greater bite force on the region can be similar between implants and teeth, because it depresses the natural teeth, positioning them closes to the depressed implant sites and equally sharing the occlusal load"
- Excursions should be evaluated after centric contacts have been corrected. The stomatognathic system produces lower forces when the posterior segments are not contacting. For this reason, all excursions on implant-protected occlusion should disclude the posterior contacts. Thus, the forces are distributed only to the anterior

segments, resulting in a decrease overall occlusal force magnitude due to the diminished muscle firing.

- In the anterior region, the lateral movement of healthy teeth ranges from 68 to 108 µm, whereas, implant movement ranges from 10 to 50 µm. This means that anterior teeth will present with more apical and lateral movement in comparison to implants, creating a bigger difference. Special care should be done when adjusting the occlusion in anterior implants.
- An occlusal force should be directed mainly along the long axis of the implant body. An angle load to the implant axis would increase the compressive forces at the crest on the opposing side, while increasing tension along the same side.
- The longer the crown height, the greater the crestal movement with any lateral force.
- The width of almost every natural tooth is wider than the width of the implant to be used to replace that tooth. The greater the width (of a tooth or an implant), the lesser the magnitude of stress into the surrounding bone.
- The elastic modulus of a tooth is closer to bone, compared to that of an implant material.
- Cortical bone is strongest in compression, whereas it will be 30% weaker in tension and 65% weaker in shear. Therefore, implant-protected occlusion has the goal of eliminating or reducing all shear load to the implant. Premature occlusal contacts produce in localized lateral loading. Elimination of premature contacts is even

more important when parafunctional habits are present because both the duration and magnitude of the occlusal force are augmented.

- Stress is defined as the magnitude's force divided by the cross-sectional area in which the force is applied. This means that the greater the area that receives a force, the less stress is produced. For this reason, wider implants will produce less mechanical stress at the crest than narrower implants. Additional implants are indicated when narrow diameter implants are used, or when the angle of load is not axial to the implant body.
- The wider the occlusal table, the more often non-axial contacts will occur.

The above mentioned recommendations provided by Misch [9] in regards to occlusion on dental implants are based on biomechanics and the bone response to load. Both topics are discussed in the following two sections.

1.2.3 Biomechanics in implant dentistry [12, 13]

Biomechanics is a discipline of biomechanical engineering which focuses on the response of biological tissues to applied loads. Dental implants will receive loads while in function. These loads vary considerably in regards to magnitude, frequency, duration and the patient's parafunctional habit. Additionally, perioral forces from the tongue and musculature may produce low, but frequent horizontal loads on the implant abutments. Moreover, the placement of nonpassive prosthesis to implant bodies can result in mechanical loads, even in the absence of occlusal loads. Shibata [14] emphasized that a deep understanding of titanium and bone biomechanical properties is "indispensable" for dental implant development and therapy. Bone properties are still not fully understood. Thus, the precise prediction of implant biomechanics has still a long way to go.

When talking about biomechanics it is important to have clear the following concepts:

Mass and force: Mass is a property of matter and it is the degree of gravitational attraction the body of matter experiences. The unity of mass in the metric systems is the kilogram (kg), whereas in the English system it is the pound mass (lbm). Force, as described by the "Newton's laws of motion" is defined as F = ma, where F is force (Newtons N), m is mass (kilograms) and a is acceleration (m/sec^2). The gravitational constant on Earth is $9.8 m/sec^2$. Therefore, mass is the determining factor in establishing the magnitude of a static load.

Forces: They can be described by magnitude, duration, direction, type and magnifications factors. Forces applied on dental implants are expressed as vectors i.e.: they have a magnitude and a direction. Forces can be described as compressive, tensile or shear. Compressive forces tend to preserve the integrity of the bone and implant interface, whereas tensile and shear forces tend to disrupt such interface. A force with the same magnitude could have different effects depending on the direction of the application of the load.

Cortical bone is stronger in compression and weaker in shear [15]. In a dental implant, a single occlusal contact most commonly results in a three-dimensional occlusal force. The position of the occlusal contact will directly influence the type of force components distribute throughout the implant system. For example, when a premature contact during occlusion is broken down into its component parts along the three dimensional axes, a large and potentially dangerous lateral component force is observed. Therefore, occlusal adjustment with the goal of eliminating the premature contact on the implant will minimize the development of such dangerous loads. So, compressive forces should typically be dominant in an implant prosthetic occlusion.

Stress: It is the manner on how a force is distributed over a surface. Thus, it is described as $\sigma = F/A$ where σ is stress (pounds per square, pascals), F is the force (Newtons or pound force) and A is the area (square inches, square meters). The magnitude of the stress depends on two factors: 1) the force magnitude, and 2) the area over which the force is dissipated. Clinically, we might decrease the force magnitude by reducing the cantilever length, reducing the offset loads or by reducing the crown height. We can optimize the area in which the force will be distributed by 1) increasing the number of implants or 2) by selecting an implant where the geometrical design maximizes the functional area.

Deformation and stress: A load applied to an implant can induce deformation of the implant and the surrounding tissues. Related to deformation is the concept of strain. The strain is directly proportional to the change from the original length.

The modulus of elasticity: Indicates the stiffness of a material. “The closer the modulus of elasticity of the implant resembles that of the contiguous biological tissues, the less the likelihood of relative motion at the implant-tissue interface” [12]. The cortical bone is at least 5 times more flexible than titanium. The larger the magnitude of the stress applied to the dental implant, the larger the difference in strain between the implant material and the bone. In this situation, it is less likely that the implant will stay attached to the bone, and the probability of fibrous tissue ingrowth is higher. Moreover, the difference of stiffness is higher for type IV which is very soft bone than it is for type I which is very dense bone. For this reason, it might be recommended to decrease the amount of strain in softer bone.

<u>Duration of a force:</u> It can affect the ultimate outcome of an implant system. Relatively low magnitude forces applied respectively over a long period of time can result in fatigue fracture. Cantilever prosthesis results in complex load reactions. In the maxilla, due to the presence of less dense bone, it is recommended to place more implants in the posterior region to increase the anteroposterior spread.

<u>Fatigue failure:</u> If an implant is subjected to an extremely high stress, then only a few cycles of loading will be tolerated before fracture occurs. On the other hand, an infinite number of loading cycles can be tolerated if they produce low stress. The stress level below which an implant can be loaded indefinitely is called its “endurance limit”. Titanium alloy exhibits a higher endurance limit than commercially pure titanium.

Fatigue failure can be diminished by reducing the extent of an applied force (strain). It can also be diminished by reducing the number of loading cycles, thus the importance to eliminate parafunctional habits.

<u>Implant length:</u> Different implant lengths were studied to evaluate the stress distribution in a 3-D finite element analysis [16]. A 176N static force was applied at the middle of the palatoincisial line angle at a 120 degree angle to the long axis. It was found that an incremental increase of implant length will cause a gradual reduction of stress at

the labial portion in the implant. Higher stress was found in the cortical bone site and was distributed along the facial bone area.

Maximum bite forces [13] These forces are affected by age, sex, degree of edentulism, and parafunction. Mericske-Stern studied the maximal occlusal force and oral tactile sensibility in dental implants [17]. Both parameters were recorded in 21 edentulous patients wearing maxillary complete dentures opposing mandibular fixed prostheses supported by dental implants. The bite force was measured using a force transducer that was 3mm high, which increased the vertical dimension when in place. The oral tactile sensitivity was studied using dynamometers and steel foils (100-10 µm). The results showed that the maximal occlusal force range from 35 to 303 N (mean of 143 N). The standard deviation indicates that occlusal forces are highly different between individuals. There was no statistically significant difference between shortened vs non-shortened arch schemes in regards to maximal occlusal force. Mandibular implants supporting fixed prosthesis are not likely to improve oral tactile sensibility due to the lack of a periodontal ligament which works as a mechanoreceptor through which information is sent to the central nervous system, as a negative feedback mechanism, regulating the occlusal load. The bite force level increases over time up to 40% when changing from full dentures to implant-supported restorations [18].

Axial forces vs off-axial forces: Axial loading forces (i.e., vertical loading on the implant crown's central fossa) produced less strain values than off-axial forces (i.e., vertical load 3 mm away from the central fossa) in an in-vitro study [19]. In this study, they used strain gauge technology and finite element analysis (FEA). One standard implant

(3.75x13mm), one mini implant (3x13mm) and one short-wide implant (5.7 x 8mm) were anchored in an epoxy resin block. Abutments and metal crowns were placed on top of the implants. Each implant received four strain gauges placed on the mesial, distal, buccal and lingual surfaces of the epoxy resin adjacent to the implants. An axial vertical load of 300 N in magnitude was applied in the central fossa (axial load). Additionally, a vertical off-axial load of 300N was applied on the distal marginal ridge of the crown, 3mm distal of the central fossa (off-axial load). The authors concluded that “all implants showed a considerable increase in strain values under off-axial loading” [19].

Implant diameter: In a finite element analysis of implants with different dimensions [20], it was shown that the stress and strain in the bone around the implant decreased by increasing the diameter of the implants from 3.7 to 5.5mm regardless of the implant length. It was also shown that lateral forces on the implants caused an important increase of the stress and strains in the bone. In another finite element analysis study [21], it was observed that maximum stress areas are located around the implant neck. The stress was greatest for narrow implants (3.6 to 4.2 mm in diameter). An increase in the implant diameter decreased the stress around the implant neck, more than an increase in the implant length.

1.2.4 Bone response to mechanical loads [22]

The implant-tissue interference is an extremely dynamic region. It undergoes changes starting on the day of implant placement, and these changes continue over time. Bone responds to both mechanical and hormonal regulation. These two pathways will usually be in opposition of each other. However, it has been shown that even in instances in which a large demand for calcium exists (primary objective of hormonal regulation), the functional loading will compete and maintain bone mass [23]. The implant-bone interface is preserved by a continuous remodeling process that replaces fatigue bone [24].

<u>The Frost's bone mechanostat theory [25]:</u> In 1892, Julius Wolff and coworkers became aware that mechanical loads can have an effect on the bone architecture in living beings, however, the mechanisms were not fully understood. In early 2000's Dr. Harold Frost developed the "mechanostat theory" to explain bone physiology. This still-evolving theory mentions the following:

- Most of our bones withstand voluntary mechanical loads. Load-bearing bones are not only limited to weigh-bearing bones. Among the load-bearing loads we can list the femurs, tibias, humeri, mandibles, maxillae, phalanges, hips, wrist, etc. "Voluntary loads" mean intentional loads. Load-bearing bones design keeps voluntary loads from causing non-traumatic fractures.
- Loads on bones produces bone strains that generates signals to which some cells can recognize and respond. Threshold ranges of these signals are determined genetically and help control bone modeling and remodeling. Repeated bone strains can produce microscopic fatigue damage within bone.
- There are set point values for bone's thresholds. 1,000-1,500 microstrains would produce an adapted response causing to strengthen a bone. At 3,000 microstrains is the threshold in and above which unrepaired micro damage can begin to accumulate. At 25,000 microstrains a bone fractures and represents the ultimate bone strength. At low microstrains, the bone will undergo disuse atrophy.

- Combining the above features forms the "bone's mechanostat". In healthy mechanostats the threshold features should apply the following rule: Threshold value in which disuse atrophy occurs < typical peaks strains cause by voluntary mechanical loads < threshold value in which unrepair microdamage starts to accumulate < threshold value in which fracture occurs.

Implication of the Frost's mechanostat in the design and use of load-bearing implants: The bone physiology suggests that the usual peak strains in the bone around the implants should be less that the threshold value that would cause microdamage, but should exceed the threshold values that would cause disuse atrophy (0-500 microstrains), and perhaps exceed the threshold value that would produce bone modeling (1,000-1,5000 microstrains). If strain is maintained in this range, this might strengthen the supporting bone and would help avoid disuse atrophy. If the bone strains exceed 3,000 microstrains, the functional adaptive capability of bone to modeling mechanism cannot be accommodated and a loss in bone mass is anticipated [25].

Mechanotransduction: It is a multistep process that includes:

1) Mechanocoupling – It is the transduction of mechanical forces into signals sensed by sensor cells
2) Biochemical coupling – It is the conversion of mechanical signals into biomechanical signals to elicit a cellular response
3) Signal transfer from sensor to effector cell
4) Effector cell response

Osteocytes have shown to have higher sensitivity to mechanical stimulation than osteoblasts [26]. However, the strain levels experienced in vivo during normal activities (0.04-0.3%) are much less than the strain levels (1-10%) required to elicit a cellular response [27].

Functional loading of bone will decrease osteocyte apoptosis disuse, whereas supraphysiologic loading will increase it, followed by Haversian modeling. Bone disuse, even in short duration, could induce hypoxia in the osteocytes which could lead to apoptosis. This hypoxic state can be reversed by physiologic loading [28].

Dynamic loading in short bouts (i.e., with rest periods inserted between loadings) have been reported to induce an increase in the number and activity of osteoblasts. It has been hypothesized that the rest periods between each cycle enhances the fluid flow through the canalicular network[29].

Strain gauges: Studies completed with strain gauges can provide important information about the response of bone to different strain levels, but these studies have limitations. Strain gauges can be placed in living bone, organ culture and cell cultures but they are technique sensitive, especially in biological tissue due to moisture, heat, irregularities of surface and poor access. This is especially significant in animal models, in which their unpredictable behavior can preclude the use of strain gauges because the animal can pull the wires away. Whereas, artificially created loads when the animal is anesthetized may not give accurate data concerning physiologic loads.

Duration of loading: “Creep” refers to the continuous deformation of a material under load. It has been shown that after 6 hours of loading, the strain will increase 3-fold.

This might explain partially why resorption occurs in the parafunctional patient, which could be a result of an accumulated creep damage. Fatigue strength is the ultimate strength below which a material can be repetitively subjected to an infinite number of cycles without failure. Threshold levels of 2,500 and 4,000 με have been noticed, above which a microdamage accumulation started [30]. The high magnitude of cycles encountered in oral function is likely accommodated in vivo due to the normal bone remodeling.

Side constraint: The biomechanical response of trabecular bone depends highly on the presence or absence of cortical plates (“side constraint”). Trabecular bone when constrained by cortical plates have 65% higher stiffness when compared with unconstrained situation. Dental implants exhibit variation in regards to the integrity of the buccal and lingual cortical plates. In some cases, both plates are absent. This is something to take into account when evaluating the bone response to loading.

Regional differences: Human trabecular bone has been reported to have differences in elastic modulus and compressive strength in different regional areas. It has been reported that a 47% to 68% higher compressive strength and elastic modulus in the anterior region is found compared to the posterior region. Moreover, the density of bone will vary depending on the region as well.

Additionally, frequency [31], duration [32], rest periods between loads [33], etc., all play a role in the bone response to loading.

Bone quality: In a finite element study, they calculated the maximum magnitude of occlusal load and generated stress at the peri-implant area for implants within four different bone qualities (Type I to IV according to the classification of Lekhom and

Zarb)[34]. Occlusal load was applied in its natural direction. This investigation suggests that an increase in implant's length and diameter will produce a reduction in the stress magnitude expressed in the cortical bone in all four types of bone qualities. Type I bone presented with the largest load-carrying ability and was able to withstand occlusal loads of 223N (for the shortest implant) to 525N (for the longest and widest implant). The load-carrying capacity of the implants inserted in Type II bone was decreased by 9.4 % to 46.4% which was dependent on the implant dimensions, whereas in type III bone the load-carrying capacity was decreased 16.4 to 60.3% compared to Type I bone. The greatest decrease was observed in Type IV bone (56% to 74% bone carrying ability decrease).

<u>Bone loss around dental implants:</u> Progression of bone loss around dental implants correlates to insufficient oral hygiene [35] [36] [37]. The accumulation of plaque deposits causes inflammation around the peri-implant mucosa which induces peri-implant marginal bone resorption. Early studies pointed out that the overloading of an implant can produce the loss of marginal bone loss or the complete loss of osseointegration [35, 38, 39].

1.2.5 Occlusal discrepancies on dental implants in the ANIMAL model

Isidor [40] reported that loss of osseointegration can be caused by excessive occlusal loading in monkeys. In this study, four Macaca Fascicularis monkeys received extractions of the first molars, premolars and incisors in the mandible. Eight months later, 5 Astra implants were placed. Two were placed in both premolar regions, and one was placed in the incisor region. In each area, one of the implants was machined, whereas the other one had a TiO_2-blasted surface. Six months after the surgical placement, the implants were uncovered and received abutments. One site received splinted restorations casted in silverpalladium alloy with supraocclusal contacts, which were high in occlusion that caused the lateral displacement of the mandible during occlusion. To ensure that supraocclusal contacts were always presents and to rule out wearing down of the prosthesis, the splinted restorations were replaced one or two times during the course of the study. The implants that received supraocclusal contacts were under a comprehensive plaque control, which included tooth brushing once a week, and subgingival cleaning once a month. In contrast, the contralateral site did not receive any prosthesis so no supraocclusal contacts were present, but were subjected to plaque accumulation by placing cotton cords around the implants. The clinical and radiographic evaluation was undertaken when the prosthesis were inserted and at 3, 6, 9, 12 and 18 months later. Their results showed that 5 out of the eight overloaded implants presented with mobility and distinct radiolucency around the extent of the implant with "none or only a small loss of height of marginal bone". The loss of integration and mobility was observed at 4.5 months and 15.5 months after loading. On the other hand, none of the implants that received plaque accumulation were mobile neither lost integration, but they presented with "increasing loss of radiographic bone height". Based on these observations, Isidor concluded that the overloading of an implant can be the main factor for the loss of osseointegration around a previously integrated dental implant, whereas plaque accumulation can be the main factor for progressive marginal bone loss height.

Miyata et al studied the influence of controlled occlusal overload on peri-implant tissue in the monkey. He published a series of articles in this topic.

1) Part I [41]: This study used 5 Macaca Fascicularis monkeys in which overload was applied without inflammation i.e. with a good oral hygiene regimen that consisted of oral hygiene once a week under general anesthesia. Two IMZ implants that measured 2.8 mm x 8mm were placed in each monkey. After 3 months of healing, the implants received superstructures that were excessive in height by 100 μm and produced a traumatic occlusal force from the lingual to the buccal side. This traumatic occlusal force was applied from 1 to 4 weeks at which moment the animals were immediately sacrificed. The monkeys were assigned in different models in the following manner: A) control (no occlusal force), B) One week occlusal force loading, C) Two weeks occlusal force loading D) Three weeks occlusal force loading E) Four weeks occlusal loading. Their results showed that all implants were osseointegrated after the initial period of healing, and remained osseointegrated after receiving excessive occlusal force for 1 to 4 weeks without gross bone loss. None of the specimens showed inflammatory symptoms i.e., redness or swelling, looseness of the implant or breakage of the superstructure. It is worth noting that this study was conducted under good oral hygiene conditions.
2) Part 2 [42]: This was a similar study as previously described but this study included experimental inflammation that was induced by using ligature wires after the second stage surgery. Their results showed that as the duration of the overload increased, the bone resorption also increased notably. This suggests that bone breakdown around the implants was accelerated when traumatic occlusion was added to inflammation around the implants.

3) Part 3 [43]: The aim of this study was to investigate different levels of traumatic occlusal force under an inflammation-free state. The prosthesis were fabricated excessively high by 100 µm, 180 µm and 250 µm. The results indicated that bone resorption around the implant tended to increase with 180 µm or more excessive height. Moreover, the 180 µm and 250 µm excess height models showed a tendency to develop greater probing depths when compared to the pre-occlusal loading conditions. Histologically, the control model did not show any notable bone changes. In the 180 µm sites slight bone resorption was observed to almost one half of the implant. In the final model with 250 µm of excess height, the vertical bone resorption reached the apex of the implant, and epithelial downgrowth was observed in both the buccal and lingual aspects.

   This suggests that the threshold of excessive height of the prosthesis at which peri-implant bone breakdown starts to occur is around 180 µm. So, bone resorption around dental implants can result due to excessive occlusal trauma even when there is no inflammatory status around the peri-implant tissue.

4) Part 4 [44]: This study intended to observe the effect of removing the occlusal trauma and introducing plaque control in monkeys. After 3 months of healing, the implants received prosthesis with excessive occlusal height of 250 µm and three models were created:

   1) Only brushing, without excessive load (for total of 8 weeks) – Model N.
   2) Only excessive load, with no brushing (for total of 8 weeks) – Model P.

3) Excessive load with no brushing (for 4 weeks), and then no excessive load with brushing – Model E.

Their results showed that in the model N (brushing, without excessive load) bone and implant contact was confirmed microscopically. Model P (excessive load, with no brushing) presented with bone resorption reaching the apical third of the implant with massive inflammatory cell infiltration. Model E showed bone resorption approaching the apical third indicating no difference with the model P and some evidence of inflammatory cell infiltrate. The authors concluded that both occlusion and inflammation need to be controlled around implants, and once peri-implantitis (bone loss) has progressed, the removal of the excessive overload and inflammations may not be sufficient to promote healing.

"Overload", mimicked by supra-occlusal contacts acting on an uninflamed peri-implant environment, did not negatively affect osseointegration and even led to a building up tissue response [6]. In this canine study, supra-occlusal contacts were defined as excessive height of the implant super-structure that led to an increase of the vertical dimension of around 3-4mm. The histological results of Kozlovsky et al showed that supra-occlusal loading significantly increased the percentage of bone-to-implant contact. In contrast, supra-occlusal contacts produced in inflammatory conditions significantly increased the plaque-induced bone resorption around dental implants. [5]

Bone strain analysis of dental implants following occlusal overload (in-vitro): The study done by Kan analyzed the bone strain around implants following occlusal loading [45]. The objective of this study was to list peri-implant bone strain patterns under quantified occlusal load on metal crowns in supra-occlusal contacts and to evaluate the biological response of bone by comparison with the critical strain set points defined by Frost's theory. In this study, two greyhound dogs underwent unilateral mandibular extractions of the third premolar and molar teeth. Six weeks after, four 4.1x8mm SLA titanium implants (Straumann) were placed. Healing caps were used and a strict daily brushing protocol implemented. After 12 weeks, non-splinted, screw-retained crowns that increased the occlusal vertical dimension by 3 mm were fabricated and placed. Baseline radiographic and clinical measures were obtained. The occlusal design was oblique to ensure for functional loading in both axial and non-axial manners. An in vivo bite force detection device was utilized to quantify the in vivo occlusal load as the dogs functioned. "To encourage optimal bite force, resilient pig skin was used to cover the device during testing", a total of 75 biting cycles were recorded and averaged. After 8 weeks of function, the peri-implant tissue was assessed. Then the animals were sacrificed and the skulls and mandibles carefully disarticulated and mounted onto a loading machine. Miniature rosette strain gauges were used to record the bone strain magnitudes and directions. Each strain gauge was individually connected to a circuit. Each dog received strain gauges which were bonded on the buccal bone lying the apex of each of the four implants, the inferior border of the mandible, between the mental foramina and the lingual bone overlying the apex of the most distal implant. All implants were successfully integrated and after 8 weeks of functioning, they all showed no signs of redness, swelling, bleeding on probing, suppuration nor mobility. Radiographically, the assessment revealed minimal crestal bone change (<0.3mm), though two implants showed slightly greater bone loss (<1mm). The average in vivo occlusal load was 434 N ± 136 N. The peak in vivo occlusal load was 795 N. In vitro, the individually absolute bone strain was 1133 microstrains, whereas the simultaneously loaded bone strain was 753 microstrains at the implant apices. For bone strain to reach the pathological overload threshold define by Frost's mechanostat (3,000 microstrains), an occlusal load of 1,344 N is required based on linear extrapolation. The authors concluded that at in vivo and in vitro conditions, peri-implant bone was not found to be under pathological overload following supra-occlusal function.

1.2.6 Occlusal discrepancies on dental implants in the HUMAN model

Merin [46] documented a case report in which peri-implant bone loss was repaired after performing occlusal adjustment only. In this report, a 63-year-old female patient, who had a history of bruxism, presented for a regular periodontal examination after 38 months of implant crown placement on #30. The radiograph indicated considerable bone loss. The patient presented with heavy occlusion on the implant. Limited occlusal adjustment was performed on #30. Five months later, the radiograph revealed repair of the peri-implant bone loss. It is important to mention that this case of bone loss did not show the characteristic features of bleeding on probing or probing depths greater than 4mm. Upon occlusal evaluation, the implant revealed heavy occlusion represented by "heavy markings on all occluding surfaces both in centric occlusion and in lateral excursions". The author performed occlusal adjustment which consisted of "grinding the areas of heavy blue markings until there was only light centric contacts". The author of this report emphasized the need for routine periodontal examinations and maintenance in order to prevent peri-implantitis and that this routine examination should include not only periodontal and radiographic findings but should include occlusion findings.

Mattheos [11] reported two similar case reports. These two cases highlight that loss of integration can happen without inflammatory signs on the marginal tissue, such as deep probing depths or bleeding, thus attributing the loss of osseointegration to other factors, such as excessive occlusal loading. The first case was a 61-year-old female who received two Straumann implants in #2 and 3 positions. These implants were restored with single-screwed restorations with even occlusal contacts and without contacts in lateral movement and protrusion. It is worth mentioning that these implants were placed simultaneously with a lateral sinus elevation. A year after delivery of the restorations, the patient complained of implant crown mobility on #3. During the clinical evaluation, no more than 1 mm "dislocation of the crown" was observed without any signs of peri-implant inflammation or deep pockets. The patient denied any trauma to the area. When attempting to unscrew the crown with the wrench, the crown rotated without loosening of the abutment screw, which indicated "spinning of the implant in the bone socket". The crown was removed after immobilizing it. The implant did not exhibit any mobility, however, loss of osseointegration based on the observed rotation was evident. Radiographically, no marginal bone was lost, however, a radiolucent halo was observed around the implant. A cover screw was placed and the #3 implant was left unloaded for 8 months. After this period of time, both #2 and #3 received splinted, screwed-retained crowns. Three months after, the implant was stable without any signs of inflammation or pocketing, and the radiographs revealed no loss of bone height or density. The second patient was a 56-year-old male who received two implants on #13, #14 areas. A screw retained restoration was delivered on #13 and a cemented restoration was delivered on #14. After 15 months, the patient complained of a lose crown on #14. The patient denied any trauma or injury. The exam revealed a fractured crown on #13 and #14 presented with “dislocation” of less than 1 mm. There were no signs of infection, inflammation or probing depths greater than 3mm. The treatment provided was adjusting the implant crown until it was “out of occlusion”. Eight months later, the implants were stable and both received splinted screw-retained restorations. Three months after the delivery of the new crowns, the implants were stable.

The loss of osseointegration reported in these 2 cases is different than that reported in plaque-induced peri-implantitis, in which marginal soft tissue is inflamed with concomitant marginal bone loss which progresses in an apical direction. Plaque-induced peri-implantitis is being described radiographically as “saucer-shaped” bone loss, in which the bone loss occurs within the limitation of the inflamed tissue. Mobility will not be present until a complete osseointegration is lost. In the above cases, mobility was the only sign, without any inflammatory signs. This might resemble the “functional mobility” or “fremitus” reported in human teeth, which were reported as cardinal signs of “trauma from occlusion” in human teeth [10].

In another case report, peri-implant bone loss was apparently caused by occlusal overload, which was corrected by eliminating the traumatic occlusion [47]. In detail, this was a 57-year-old female that received three 16mm long implants in the right quadrant. These implants were stable and did not present any bone loss other than normal bone remodeling. However, 9 years later, the left tooth-supported bridge collapsed due to decay. The restorative dentist removed the left teeth and placed an overdenture. Six months after wearing the overdenture, the patient presented to the periodontist office wearing a very unstable overdenture and severe bone loss that extended to the sixth thread of two implants. A new well-fitted removable prosthesis was fabricated and delivered. The bone lesions begin to heal within 3 months after elimination of the traumatic condition. Four years after delivery of the well-fitted restoration, the bone is near the level of the first thread on the 2 implants that experienced bone loss.

Uribe [48] presented a case report in which marginal peri-implantitis was apparently associated with occlusal overload. In addition to the clinical findings, he included a histopathological analysis. In detail, this was a 46 year-old male, who received a SLA Straumann implant on #19 which was restored with a cemented crown. The implant presented with slight erythema and a pocket of 6 mm and bleeding on probing. Upon occlusal evaluation with articulating paper, a premature contact was evident. The treatment consisted of a combination of occlusal adjustment and surgical treatment. The occlusal adjustment included the reduction of the prosthetic crown. The surgical treatment included the elevation of a mucoperiosteal flap, removal of the soft tissue around the implant, decontamination with chlorhexidine and saline, and placement of bone autograft. The soft tissue biopsy result revealed dense fibrous connective tissue with few inflammatory cells, which according to previous literature is different from microbial induced peri-implantitis. After 12 months from treatment, the implant was stable. The authors emphasized the importance of occlusal adjustment for the success of the treatment.

Also, they emphasized the need for histologic evaluation of the tissue around the implant to determine the cause for implant failure.

Quirynen et al. studied the effect of overload on Branemark fixtures [49]. From 1982 to 1989, a total of 467 consecutive edentulous patients were rehabilitated ad modum Branemark. The patients were recalled every 6 months by the same periodontist and prosthodontist. The follow up time was 3 years. The occlusal overload was evaluated in 84 patients that had fixed full prostheses. If the antagonist was a denture, balanced occlusion was attempted. In all other cases, cuspid-protected occlusion was present in 44% of the cases, groups function in 38% of the cases, and 17% of the cases presented with cuspid/anterior contact. The diagnosis of parafunctional activity was made if excessive occlusal wear or crown fractures was correlated with tooth clenching or bruxism. They found that failing or failed implants were observed if there was a lack of anterior contact, or the presence of parafunctional activity.

Management of occlusion over implants in patients with centric bruxism (clenching): [50] [51]The author presents 3 cases that had centric bruxism (clenching). The implants were restored with “internally reinforced gold metal ceramic technology (Captek)” restorations. In his rationale, the author mentions that there is currently debate in regards to the effect of harder restorations placed over implants. However, it seems that this is contradictory to nature, since the masticatory system is designed to dissipate the occlusal loads. A natural tooth presents with the hardest tissue in the human body (enamel), but it is layered with supporting dentin that is 4.7 times less hard. Additionally, the periodontal ligament functions as a shock absorber. Thus, a tooth is the perfect combination of maximum hardness along with natural flexibility, which under healthy condition can function over 90 years. The periodontal ligament works as a mechanoreceptor through which information is sent to the central nervous system, as a negative feedback mechanism, regulating the occlusal overload. In the other hand, implants are solid pieces embedded into bone and which are restored many times with harder material than enamel, and which oral tactile perception is not as sensitive as the periodontal ligament. Based on these points, it is possible to infer that dental implants are more sensitive to occlusal overload than natural teeth. In the cases that the author presents, the implants were restored with internally reinforced gold metal ceramic technology (Captek) restorations. These crowns have inner layers of gold that have the ability to be compressed, dissipating some occlusal forces. In these case series, the crowns were successfully restored with a 10 year follow up. The author recommended the following suggested occlusal scheme:

- The restoration must have a reduced occlusal buccal-lingual plane.
- It must have a "passive" occlusion, in which, only the working opposing cusp makes contact with the crown at 3 or 4 small points when the natural teeth are in active contact in maximum occlusion.
- Occlusal forces must be directed to the longitudinal axis of the implant.
- It must have immediate disclussion on any eccentric movements.

The parameters suggested by the author are based on clinical experience only, without any scientific validity. Research is warranted to evaluate the compression capacity of these reinforced gold metal ceramic copings.

The effect of maximum bite force on marginal bone loss around implants in patients was studied by Jofre in 2010 [7]. This study looked at mini implants that were supporting a mandibular overdenture. The patients were allocated randomly into two groups: one group received two single ball-type mini-implants and the other group received two mini-implants splinted with a prefabricated bar. The maximum bite force was recorded using a pressure-sensitive sheet and marginal bone loss was measured using standardized radiographs of each mini-implant at the baseline and at 5, 7, 10, and 15 months after surgery. His results showed that there was no relationship between the maximum bite force and the marginal bone loss on the mini-implants. However, this study only included patients wearing overdentures, in which most of the support lays on the mucosa while implants are mainly used to enhance retention rather than support. This could be a possible reason for their results.

1.2.7 Occlusal discrepancies on dental implants REVIEWS

In a review of the literature in regards to current concepts in implant occlusion, Ben-Gal [52] concluded that "contact distribution between the prosthesis and opposing jaw play a substantial role in preserving the prosthesis, but have a lesser effect on implant survival and bone loss".

There are multiple reviews on the topic [53], but they appear to present the authors opinions and clinical expertise.

Naert, in a review of the effect of the occlusal load in peri-implant bone [5], mentions that although the amount of stress and strain can be defined at the exterior bone surface via strain gauge technology, the stress and strain produced within the implant-bone interface remains impossible to quantify today in either an in vivo animal model or clinically in a human study. Because of this difficulty it remains challenging, if not impossible, to establish an association between occlusal loading and implant failure/peri implant disease.

2. RESEARCH PROTOCOL

2.1 Materials and Methods

This cross-sectional study was conducted at the Graduate Periodontics Department of Texas A&M University Baylor College of Dentistry, and it was in compliance with IRB regulations. The inclusion criteria included patients that received at least one dental implant which was restored with a single-unit crown and had been in function for at least 1 year were included. The exclusion criteria were patients wearing implant overdentures, implant supported bridges (or other prosthetic options that were not single-unit crowns), and if they had interim implant crowns. Patients that fulfilled these criteria were contacted by phone, or face-to-face when they attended their regular dental appointment. They were asked to attend a 1-hour appointment. During this appointment, the patient signed an informed consent document and underwent a clinical and radiographic evaluation. Information regarding age, sex, smoking, diabetes and time from implant crown placement was obtained.

The occlusal evaluation included recording the type of occlusal contact during maximal intercuspidation (MI) i.e. “heavy”, “light” or “no contact”, using articulating ribbon. A contact was classified as “heavy” when then mark left on the implant crown by the articulating ribbon during MI was more pronounced (darker or larger) than the one observed on the adjacent teeth. A contact was classified as “light” when the mark left by the articulating ribbon was lighter than the one observed on the adjacent teeth. A contact was classified as “no contact” when no contact mark was observed on the implant crown whatsoever. In addition, the presence or absence of excursive contacts on the implant during working (W), balancing (B), and protrusive (Pr) movement was recorded (Figure 1).

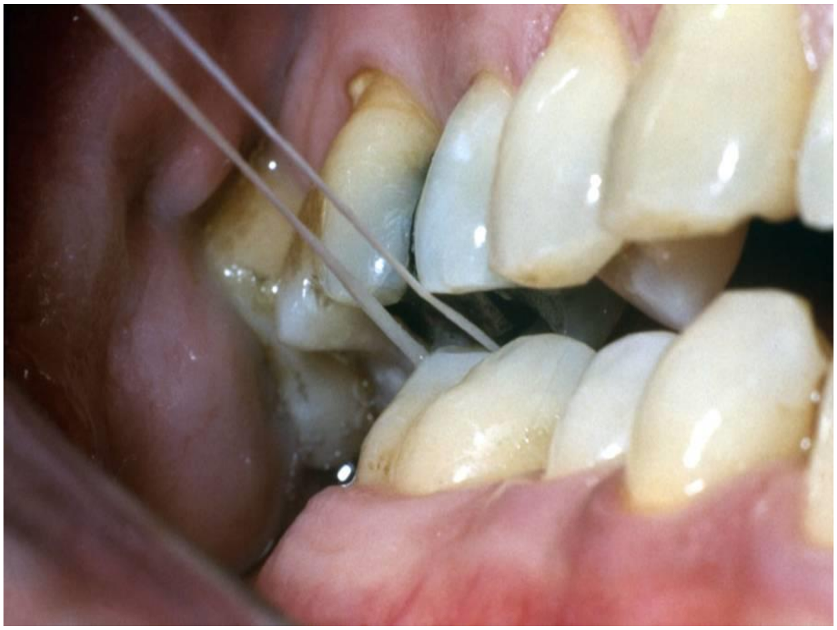


Figure 1: Presence of contact during balancing (B) movement. Photo courtesy of Dr. Steve Harrel.

Moreover, the implant was classified in two groups: “implant-protected occlusion” or “no implant-protected occlusion”. In brief, an implant presented with “implant-protected occlusion” if the implant has no heavy contact during MI, no contacts during balancing and protrusive movements, and no premature contact from centric relation to centric occlusion [9]. In addition, the computerized analysis of occlusion was completed using a commercially available device (T-Scan® - Tekscan, Boston, Massachusetts. Figure 2). The relative Maximum Bite Force (rMBF) on each implant was recorded four times and the mean rMBF per implant was calculated (Figure 3). Additionally, the disclussion times during working (W), balancing (B), and protrusive (Pr) movements were recorded.

Figure 2: T-Scan® device utilized for the computerized analysis of occlusion

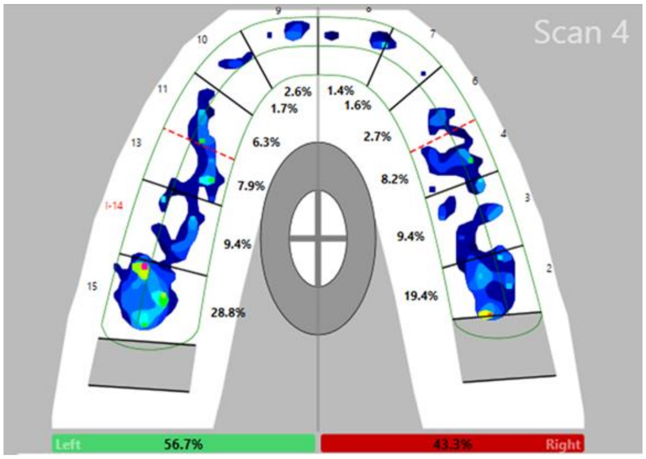


Figure 3: Computer view of T-Scan ® recordings. In this example, #14 is an implant (marked as I-14) and presents with a relative Maximum Bite Force (rMBF) of 9.4%

To evaluate the implant condition, several parameters were evaluated. These included implant mobility, suppuration, pain upon vertical percussion, bleeding on probing (BOP), and probing depths (PD) in six sites per implant using a plastic UNC-15 probe. Periapical and vertical bite wing radiographs were taken with a Planmeca ProStyle radiograph machine (Roselle, Illinois) set it up to 63kVp, 8 mA, 0.08 sec and using a digital sensor. In order to evaluate the implant crestal bone levels, all images were transferred and calibrated using MiPACS software. The crestal bone level was measured in mm and it was defined as the distance from the implant platform to the first implant-to-bone contact on both the distal and mesial aspects of the dental implant. All radiographic measurements were completed in a dark room and done twice. The amount of bone loss was calculated by subtracting the initial crestal bone level (at the time of implant placement or crown delivery) to the crestal bone level at the time of the study evaluation. Detailed information regarding the initial (baseline) radiograph settings and machinery used was not available. Moreover, an implant was classified as having "peri-mucositis" when it presented with BOP and had NO bone loss [54]. An implant was classified as having "peri-implantitis" when it fulfilled the following conditions: presence of BOP, PD >=5mm, bone loss >= 2mm [54, 55 56].

The statistical power analysis to determine the sample size was calculated using a statistical power of 80% and a statistical significance of 5% (α=0.05). In order to find a correlation of 0.4, the required sample size was 44 patients. Data analysis was completed using software systems (Microsoft Excel 2015 and IBM SPSS Statistics 23).

2.2 Results

A total of 206 patients that fulfilled the inclusion criteria were contacted from July 2014 to September 2015. Forty-four patients (77 implants) agreed to participate and were recruited. Three implants were excluded from the analysis because one of them presented with a complete fractured crown, and two others received bone grafts and their occlusal contacts were altered at the time of regenerative surgery. Therefore, 74 implants were included in the statistical analysis. 58 implants were restored by a prosthodontist that practice within the Texas A&M Baylor College of Dentistry and all restorations in these groups were made in the same lab. The remaining 16 implants were restored at the undergraduate implant clinic of Texas A&M University Baylor College of Dentistry by different students.

The descriptive statistics of the sample are represented in Table 1. The mean patient age was 65 (±11.4) years, with a range of 31 to 79 years. Forty four patients were females (59.5%), whereas 30 patients were males (40.5%). Four patients reported being smokers (5.7%) and 4 patients reported having diabetes (5.7%). Regarding implant characteristics, 30 implants (40.5%) presented with horizontal offset (platform switch), whereas 44 implants (59.5%) did not. Also, the vertical offset was recorded, i.e. whether the implant was "bone level" or "tissue level". It was observed that 5 implants (6.8%) were "tissue level", and 69 implants (93.2%) were "bone level". Most of the restorations were screw-retained (64 implants, 86.5%), while only 10 implants (13.5%) received cemented restorations. The mean time from crown placement was 56.7 months with a range of 12 to 132 months.

No implant presented with suppuration, mobility or pain upon vertical percussion. The mean implant deepest probing depth was 3.66 mm (±1.17mm) with a range of 1 to 7mm. The mean radiographic bone loss was -0.18 mm (±0.83mm) with a range of -3.43 to 1.40. A negative value indicates bone loss, whereas a positive value indicates bone gain. A total of 42 implants (57%) presented with peri-mucositis. Moreover, 3 implants presented with peri-implantitis; however, due to the small number, this variable was excluded from the statistical analysis.

In regards to the occlusion status (Table 2 and 3), it was observed that the type of contact during maximum intercuspation was "light" in 40 implants, "heavy" in 29 implants, and "no contact" was presented in 5 implants. In regards to excursive movements, 20 implant crowns presented with contact on the working site, whereas 4 and 7 implant crowns presented with balancing and protrusive contacts, respectively. When using the definition of "implant-protected occlusion", 38 implant crowns presented with "implant-protected occlusion", and 36 implant crowns presented with "no implant-protected occlusion". When considering the T-Scan variables, the mean relative maximum bite force on the implant was 10% (±9.57) with a range of 0% to 44%, this means that at least one implant did not receive any force whatsoever (0%) during maximum bite force (MBF), while at least one implant received 44% of the force while MBF. The mean implant disclussion time when the patient was asked to move the jaw towards the working side was 1.06 sec (±0.94), whereas it was 0.58 sec (±0.66) and 0.42 (±0.59) sec when the patient was asked to move the jaw towards the balancing and protrusive, respectively.

When evaluating the peri-mucositis (Tables 4), the statistical analysis using the chi-square test showed that none of the occlusion variables had an association with the peri-mucositis condition ($p>0.05$). Graph 1 to 5 present bar charts supporting the chi-square results from Table 4.

When evaluating the implant deepest probing depth (Table 5 and 6) the statistical analysis using the Mann-Whitney, Kruskall Wallis and Generalized Equation Models statistical tests did not reveal any association with any of the occlusal variables ($p>0.05$).

Similarly, when evaluating the radiographic bone loss (Tables 7 and 8) the statistical analysis revealed that none of the occlusal variables had an association with the radiographic bone loss. ($p>0.05$).

Table 1. Descriptive statistics

Age (years)	
Mean (±SD)	65.0 (±11.4)
Median	67.5
Range	31 to 79
Gender	
Female	44 (59.5%)
Male	30 (40.5%)
Smoking status	
Non-smoker	66 (94.3%)
Smoker	4 (5.7%)
Diabetes	
No	66 (94.3%)
Yes	4 (5.7%)
Horizontal offset (platform switch)	
No	44 (59.5%)
Yes	30 (40.5%)
Vertical offset (level)	
Bone level implant	69 (93.2%)
Tissue level implant	5 (6.8%)
Type of restoration	
Screw-retained	64 (86.5%)
Cemented	10 (13.5%)
Time from restoration (months)	
Mean (±SD)	56.7 (±25.0)
Median	60
Range	12 to 132

Table 2. Occlusal characteristics

Occlusal characteristics			
		N	**Percentage**
Type of contact	No contact	5	6.8%
	Light contact	40	54.1%
	Heavy contact	29	39.2%
Working contact	Yes	20	27.0%
	No	54	73.0%
Balancing contact	Yes	4	5.4%
	No	70	94.6%
Protrusive contact	Yes	7	9.5%
	No	67	90.5%
Implant-protected occlusion	Yes	38	51.4%
	No	36	48.6%

Table 3. Occlusion status T-Scan ®

Occlusion status with T-Scan ®			
	Mean (±SD)	**Median**	**Range**
Implant relative Maximum Bite Force (rMBF)	10%		0 - 44%
Implant Disclusion Time WORKING	1.06 sec (±0.94 sec)	0.82 sec	0 - 4.12 sec
Implant Disclusion time BALANCING	0.58 sec (±0.66 sec)	0.40 sec	0 - 2.88 sec
Implant Disclusion Time PROTRUSIVE	0.42 sec (±0.59 sec)	0.24 sec	0 - 3.88 sec

Table 4. Statistical analysis between peri-mucositis status and occlusal variables

Peri-mucositis					
		Yes	**No**	**p**	**Graph number**
Type of contact	No contact	3 (7%)	2 (6%)	0.72ˇ	Graph 1
	Light contact	21 (50%)	19 (59%)		
	Heavy contact	18 (43%)	11 (34%)		
Working contact	Yes	11 (26%)	9 (28%)	0.85ˇ	Graph 2
	No	31 (74%)	23 (72%)		
Balancing contact	Yes	2 (5%)	2 (6%)	0.58ˇ	Graph 3
	No	40 (95%)	30 (94%)		
Protrusive contact	Yes	1 (2%)	6 (19%)	0.2ˇ	Graph 4
	No	41 (98%)	26 (81%)		
Implant-protected occlusion	Yes	21 (50%)	17 (53%)	0.79ˇ	Graph 5
	No	21 (50%)	15 (47%)		

ˇ Chi-square test

p > **0.05** No association was found between the occlusal variables and peri-mucositis

Table 5. Statistical analysis between PD and categorical occlusal variables

Implant probing depth (PD)						
		N	Mean (±SD)	Median	Range	p
Type of contact	No contact	5	4 (±1.87)	4	2 - 7mm	0.979*
	Light contact	40	3.68 (±1.23)	4	1 - 6mm	
	Heavy contact	29	3.62 (±0.98)	4	2 - 5 mm	
Working contact	Yes	20	3.85 (±0.81)	4	3 - 5 mm	0.36⁎
	No	54	3.611 (±1.28)	4	1 - 7 mm	
Balancing contact	Yes	4	4.25 (±1.71)	4.5	2-6mm	0.34⁎
	No	70	3.64 (±1.14)	4	1-7mm	
Protrusive contact	Yes	7	3.1 (±1.22)	3	2-5mm	0.22⁎
	No	67	3.73 (±1.16)	4	1-7mm	
Implant-protected occlusion	Yes	38	3.68 (±1.23)	4	1-7mm	0.96⁎
	No	36	3.67 (±1.12)	4	2-6mm	

*** Kruskal - Wallis test**

⁎Mann-Whitney test

p > **0.05** No association was found between the occlusal variables and implant PD

Table 6. Statistical analysis between PD and interval occlusal variables

Implant probing depth (PD)	
	Sig. (p)
Implant relative Maximum Bite Force (MBF)	0.720æ
Implant Disclusion Time WORKING	0.603æ
Implant Disclusion time BALANCING	0.600æ
Implant Disclusion Time PROTRUSIVE	0.471æ

æGeneralized Equations Model (GEE)

p > **0.05** No association was found between the occlusal variables and implant PD

Table 7. Statistical analysis of radiographic bone loss (mm) by occlusal variables

Radiographic bone loss (mm)						
		N	Mean (±SD)	Median	Range	p
Type of contact	No contact	5	-0.61 (±0.84)	-0.25	-2.07 to 0	0.43*
	Light contact	40	-0.15 (±0.9)	-0.03	.43 to 1.2	
	Heavy contact	28	-0.16 (±0.74)	-0.05	1.66 to 1.	
Working contact	Yes	54	-0.48 (±0.99)	-0.28	3.43 to 0.	0.17⁎
	No	19	-0.08 (±0.76)	-0.3	2.07 to 1.	
Balancing contact	Yes	3	0.5 (±0.96)	0.64	.52 to 1.3	0.17⁎
	No	70	-0.21 (±0.83)	-0.09	3.43 to 1.	
Protrusive contact	Yes	6	0.18 (±0.65)	0.05	.58 to 1.3	0.32⁎
	No	67	-0.22 (±0.85)	-0.13	3.43 to 1.	
Implant-protected occlusion	Yes	38	-0.28 (±0.92)	-0.21	-3.43 to 1	0.46⁎
	No	35	-0.08 (±0.72)	0	1.66 to 1.	

*** Kruskal - Wallis test**

⁎Mann-Whitney test

p > **0.05** No association was found between the occlusal variables and radiographic bone loss

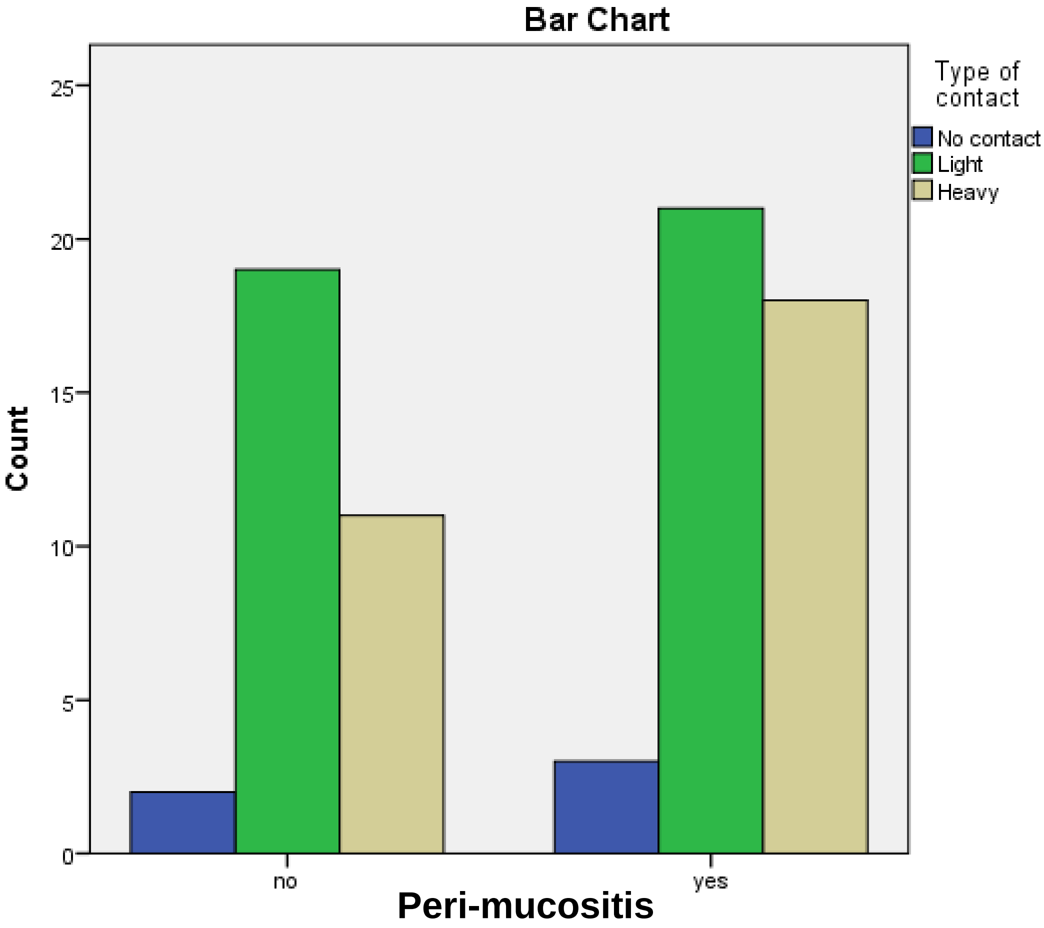
Table 8. **Statistical analysis of radiographic bone loss (mm) by interval occlusal variables**

Radiographic bone loss	
	Sig. (p)
Implant relative Maximum Bite Force (MBF)	0.998^{æ}
Implant Disclusion Time WORKING	0.589^{æ}
Implant Disclusion time BALANCING	0.067^{æ}
Implant Disclusion Time PROTRUSIVE	0.555^{æ}

^{æ}Generalized Equations Model (GEE)

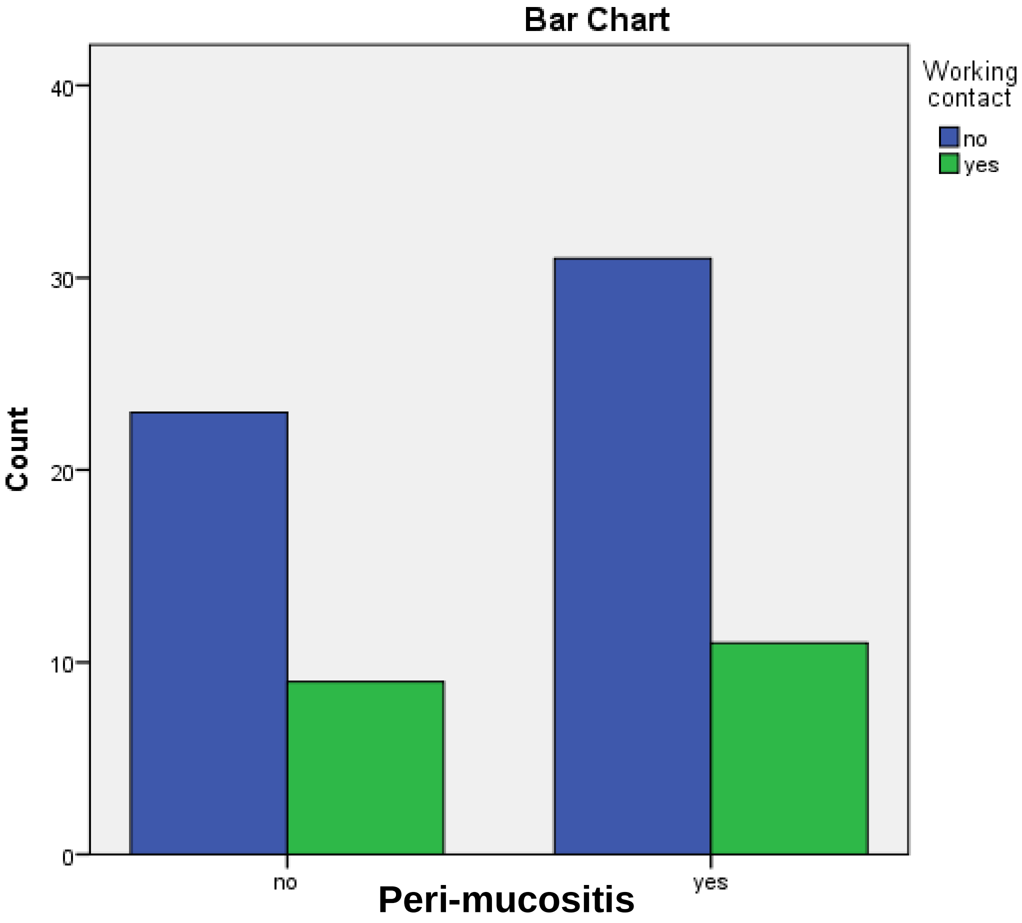
p > **0.05** No association was found between the occlusal variables and radiographic bone loss

Graph 1. Bar chart of the "Peri-mucositis" status and type of occlusal contact



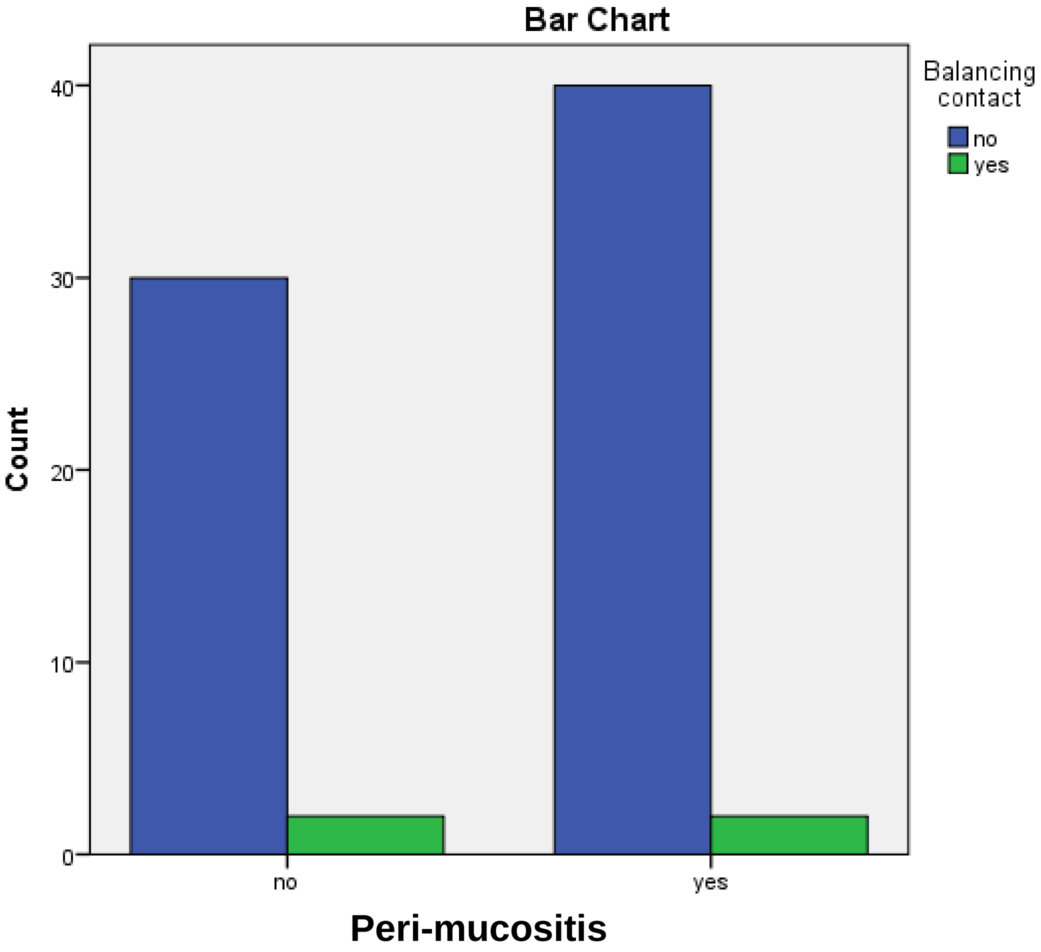
Legend: Peri-mucositis: Yes: Implant presented with peri-mucositis, No: Implant did not present with peri-mucositis. **Count:** Number of implants that presented with peri-mucositis by type of contact "heavy", "light" and "no contact"

Graph 2. Bar chart of the "Peri-mucositis" status and working contact



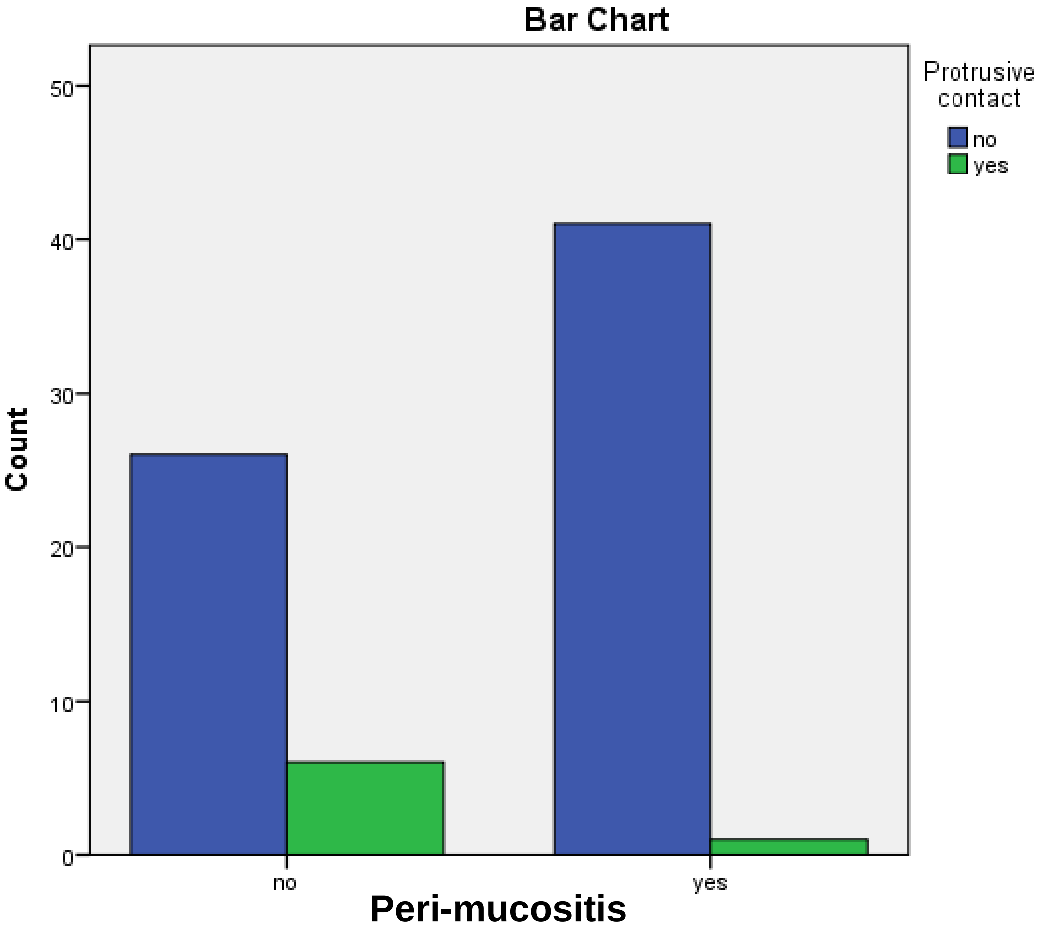
Legend: Peri-mucositis: Yes: Implant presented with peri-mucositis, No: Implant did not present with peri-mucositis. **Count:** Number of implants that presented with peri-mucositis by presence (yes) or absence (no) of implant contact on the working side

Graph 3. Bar chart of the "Peri-mucositis" status and balancing contact



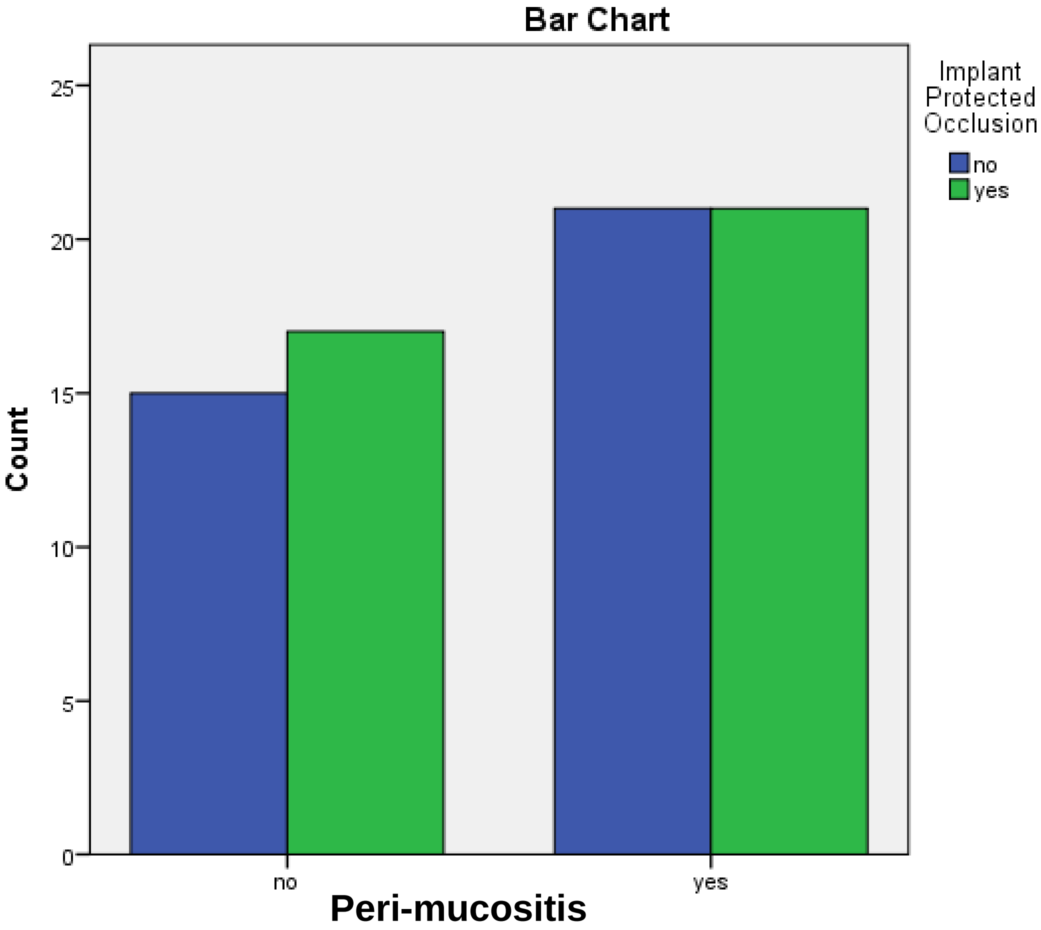
Legend: Peri-mucositis: Yes: Implant presented with peri-mucositis, No: Implant did not present with peri-mucositis. **Count:** Number of implants that presented with peri-mucositis by presence (yes) or absence (no) of implant contact on the balancing side

Graph 4. Bar chart of the "Peri-mucositis" status and protrusive contact



Legend: Peri-mucositis: Yes: Implant presented with peri-mucositis, No: Implant did not present with peri-mucositis. **Count:** Number of implants that presented with peri-mucositis by presence (yes) or absence (no) of implant contact on the protrusive side.

Graph 5. Bar chart of the "Peri-mucositis" status and "Implant-protected occlusion"



Legend: Peri-mucositis: Yes: Implant presented with peri-mucositis, No: Implant did not present with peri-mucositis. **Count:** Number of implants that presented with peri-mucositis by presence (yes) or absence (no) of "Implant-Protected occlusion.

2.3 Discussion

This cross-sectional study evaluated the association between occlusion and the peri-implant condition around single unit dental implants. In order to evaluate the occlusion status, we utilized clinical and computerized methods. To evaluate the peri-implant condition, we used clinical and radiographic measurements such as implant probing depth, bleeding on probing, mobility, suppuration, pain upon vertical percussion, and radiographic crestal bone level. When analyzing these variables, we did not find a statistically significant association between the occlusal variables with the peri-implant condition variables that were included in this study. While the influence of occlusion on the development of peri-implant disease remains plausible from a biomechanics and bone physiology standpoint, the data from our study does not support this conclusion. More studies with larger sample size may be required to analyze the association between implant status and occlusal status.

Moreover, in order to increase the homogeneity among the implant restorations and eliminate variables such as operator experience, we recruited most of the implants from the records of a faculty prosthodontics practice. 58 implants were restored by one practicing prosthodontist (JG) while all other 16 implants were restored at the undergraduate implant clinic by different students. Having a highly experienced prosthodontist as the main provider might explain that very few implants presented with pathologic contacts i.e. excursive contacts (4 and 7 implants presented with balancing and protrusive contacts, respectively). While this shows that most the implants received an optimal occlusal scheme, this might have impacted our statistical analysis by not allowing equal sample numbers among groups. Allocating patients into two groups that would receive randomly excursive contacts or not is not ethical.

The mean radiographic bone loss was -0.18 mm (±0.83mm). This is compatible with implant health conditions and normal remodeling. Very few implants presented with pronounced radiographic bone loss (up to -3.43 mm), while few other implants presented with considerable crestal bone gain (up to 1.40mm). This wide range of crestal bone gain or loss did not seem to correlate to the occlusion variables. In our study in which most were properly restored single implants with minimal occlusal discrepancies, we see very little marginal bone loss. However, in a larger study with multiple restoring doctors of variable experience one would expect to see a greater correlation between occlusal discrepancies and bone loss.

In our study, we were able to identify 3 implants that presented with peri-implantitis. Due to the limited number of peri-implantitis cases observed in this study, it was not possible to perform a statistical analysis. Moreover, 42 implants (57%) presented with peri-mucositis. The prevalence of peri-mucositis observed in this study is higher than that previously reported in the literature, around 48% in implants with 9 to 14 years of follow up [57]. The occlusal variables did not show a statistically significant association with the peri-mucositis status.

It seems to be that peri-mucositis and peri-implantitis are multifactorial. The role of plaque [58], history of periodontal disease [59], smoking [60], and diabetes [60] among other factors have been linked with higher prevalence of peri-implant diseases.

In the animal model the effect of occlusion on the peri-implant condition is controversial. Isidor [40] reported loss of osseointegration can be caused by excessive occlusal loading in monkeys. Similarly, Miyata [42] applied overload in inflammatory conditions i.e. without plaque control, and found that bone breakdown around the implants was accelerated when traumatic occlusion was added to inflammation around the implants. Furthermore, the same author suggested that a threshold of excessive height of the prosthesis of 180 µm is necessary for peri-implant bone to break down [43]. The same author mentions that once bone loss has progressed, the removal of the excessive overload and inflammation may not be sufficient to promote reversible healing [44]. Similarly, Naert observed that supra-occlusal contacts in the presence of inflammatory conditions significantly increased the plaque-induced bone resorption around dental implants. [5]. In contrast to all these results, “overload”, defined as supra-occlusal contacts acting on a non-inflamed peri-implant environment, did not negatively affect osseointegration and even led to a building-up tissue response [6]. In this canine study, supra-occlusal contacts were defined as excessive height of the implant super-structure that led to an increase of the vertical dimension of around 3-4mm. The histological results of Kozlovsky et al showed that supra-occlusal loading significantly increased the percentage of bone-to-implant contact. Heitz-Mayfield in an animal study found that excessive occlusal load does not affect peri-implant bone levels [61]. Moreover, in a study done by Kan, he analyzed the bone strains around implants following occlusal loading [45] and concluded that at in vivo and in vitro conditions, peri-implant bone loss was not found to occur under pathological overload conditions.

In the human model, there are multiple case reports that mentioned the role of occlusion as a factor for peri-implant tissue breakdown. Merin [46] documented a case report in which peri-implant bone loss was repaired after performing occlusal adjustment only. Mattheos [11] reported two similar case reports. These two cases highlight that loss of osseointegration can happen without inflammatory signs on the marginal tissue, such as deep probing depths or bleeding, thus attributing the loss of osseointegration to other factors, such as excessive occlusal loading. Tawil [47] in another case report, mentions that peri-implant bone loss was apparently caused by occlusal overload, which was corrected by eliminating the traumatic occlusion. Uribe [48] presented a case report in which marginal peri-implantitis was apparently associated with occlusal overload. In addition to the clinical findings, he included a histopathological analysis. The soft tissue biopsy result revealed dense fibrous connective tissue with few inflammatory cells, which according to previous literature is different from microbial induced peri-implantitis.

A cross-sectional study conducted by Quirynen et al. studied the effect of overload on Branemark fixtures [49]. The occlusal overload was evaluated in 84 patients that had fixed full prosthesis. If the antagonist was a denture, balanced occlusion was attempted. In all other cases, cuspid-protected occlusion was present in 44% of the cases, group function in 38% of the cases, and 17% of the cases presented with cuspid/anterior contact. The diagnosis of parafunctional activity was made if excessive occlusal wear or crown fractures was correlated with tooth clenching or bruxism. They found that failing or failed implants were observed if there was a lack of anterior contact, or the presence of parafunctional activity. Within the review of published literature on this subject, no comparable studies were found that could compare with our results, this makes our study the first one to report in this topic using both clinical and computerized methods to analyze the occlusion. . No studies were found that had a similar protocol than in our study as to compare our results with. It is important to conduct studies in this topic with bigger sample size.

2.4 Conflict of Interest

The authors reported no conflict of interest. The study was completed using funds from the Graduate Fund of the Texas A&M Baylor College of Dentistry. The T-Scan® device and sensors were provided by Tekscan (Boston, Massachusetts) during the length of the study.

3. CONCLUSIONS

Within the limitations of the present study, it may be suggested that occlusion in single-unit dental implants does not demonstrate an association with the peri-implant condition in a university setting.

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