A Positive Correlation Between Occlusal Trauma and Peri-implant Bone Loss: Literature Support

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Occlusal trauma may be defined as an injury to the attachment apparatus as a result of excessive occlusal force.[1] There is currently controversy as to the role of occlusion in the bone loss observed after the delivery of an implant prosthesis.[2] There is generalized agreement that early implant failure may be associated with overload (Fig. 1).[3,4] However, some articles state that peri-implant bone loss without implant failure is primarily associated with biological formations or complications (Fig. 2).[5-7] Other authors suggest a correlation of crestal bone loss to occlusal overload.[2,8] The determination of the etiology of bone loss around dental implants is needed to minimize its occurrence and to foster long-term peri-implant health, which ultimately determines implant prosthesis survival. The purpose of this article is to review the literature that focuses on suggesting a relationship between bone loss and biomechanical stress.

METHODS

To establish a correlation between marginal bone loss and occlusal over-load, related articles from cellular biomechanics, engineering principles, mechanical properties of bone, physiology of bone, implant design biomechanics, animal studies, and clinical reports were obtained from a MEDLINE and hand search of English-language publications that had been written over the last three decades.

Cellular Biomechanics

Bone remodeling at the cellular level is controlled by the mechanical environment of strain.[9] Strain is defined as the change in length divided by the original length; and the units of strain are given in percent. The amount of strain in a material is directly related to the amount of stress applied.[10] Occlusal stress applied through the implant prosthesis and components can transmit stress to the bone-implant interface.[9] The amount of bone strain at the bone-implant interface is therefore directly related to the amount of stress applied through the implant prosthesis. Mechanosensors in bone respond to minimal amounts of strain, and microstrain levels 100 times less than the ultimate strength of bone may trigger bone remodeling.[11]

One of the earliest remodeling theories for a direct relationship between stress and the magnitude of bone remodeling was proposed by Kummer in 1972.[12] More recently, Frost reported on the cellular reaction of bone to different microstrain levels.[13,14] He observed that bone fractures at 10,000 to 20,000 microstrain units (1 to 2% deformation). However, at levels 20 to 40% of this value (4,000 units), bone cells may trigger cytokines to begin a resorption response. In other words, excessive bone strain may not only result in physical fracture, but may also cause bone cellular resorption. Therefore, the hypothesis that occlusal stresses beyond the physiologic limits of bone may result in strain in the bone significant enough to cause bone resorption is plausible from a cellular biomechanics standpoint. To date bone cellular studies have not replicated these bone

The relationship between occlusal overload and peri-implant bone loss remains a controversial topic in implant dentistry. A causal relationship between the incidence of marginal bone loss next to an implant and occlusal overload implies a treatment plan and occlusal scheme would benefit from a force management approach. A MEDLINE-assisted and hand search of peer-reviewed English literature and relative textbooks were used for a selective review of articles addressing biomechanical stress and bone loss in cellular biomechanics, engineering principles, mechanical properties of bone, animal studies, clinical reports, bone physiology, and implant design biomechanics. These papers demonstrate occlusal overload on implants may increase the incidence of marginal bone loss. (Implant Dent 2005;14:108–116)
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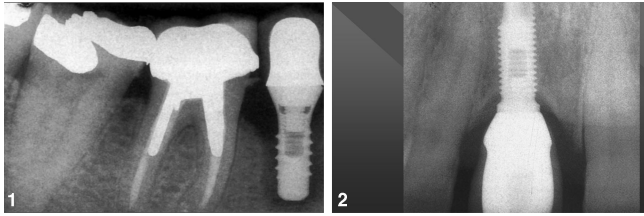
Fig. 1. Occlusal overload caused the failure of the second premolar implant restoration. This patient has parafunction and the restoration had lateral contacts in mandibular excursions.
Fig. 2. Crestal bone loss after the first year of prosthetic loading is often observed. This periapical radiograph demonstrates 2 mm of bone loss compared to the original bone crest at implant insertion.

conditions next to a dental implant. However, cytokines in the bone-to-implant interface tissue obtained from failed hip replacement devices associated with bone loss have been reported in humans.[15]

Engineering Principles

The relationship between stress and strain determines the modulus of elasticity (stiffness) of a material.[10] Hence, the modulus conveys the amount of dimensional change in a material for a given stress level. The modulus of elasticity of a tooth is similar that of to cortical bone.[16] Dental implants are typically fabricated from titanium or its alloy. The modulus of elasticity of titanium is 5 to 10 times greater than that of cortical bone.[16] An engineering principle called "the composite beam analysis" states that when two materials of different elastic moduli are placed together with no intervening material and one is loaded, a stress contour increase will be observed where the two materials first come into contact.[17] In an implant-bone interface these stress contours are of greater magnitude at the crestal bone region. This phenomenon was observed in both photoelastic (Fig. 3) and 3-dimensional finite element analysis (Fig. 4) studies when implants were loaded within a bone simulant.[18,19] These authors note that the marginal bone loss observed clinically and radiographically around implants follows a similar pattern as the stress contours in these reports.

Bone Mechanical Properties

Bone density is directly related to the strength and elastic modulus of bone.[20] Hence, in denser bone there is less strain under a given load compared to softer bone. As a result, there is less bone remodeling in denser bone compared to softer bone under similar load conditions.[13] A decrease in bone remodeling can result in a reduction of bone loss. In a prospective human study, Manz observed that the amount of marginal bone loss next to an implant was related to the density of bone.[21] The peri-implant bone loss from implant insertion to the implant uncovery surgery was similar for all bone qualities. However, 6 months after prosthesis delivery the additional peri-implant bone loss observed radiographically ranged from 0.68 mm for quality 1, 1.1 mm for quality 2, 1.24 mm for quality 3, and 1.44 mm for quality 4 type bone. In other words, the more dense the bone, the less peri-implant bone loss was observed after prosthesis delivery. Since bone density is related to bone strength, elastic modulus, bone remodeling, and marginal bone loss, these entities may be related to each other.

Animal Studies

Several animal studies in the literature demonstrate the ability of bone tissue to respond to a dental device.

For example, Hoshaw et al inserted dental implants into a dog femur perpendicular to the axis of the long bone and perpendicular to the direction of the osteons.[22] After applying a tensile load to the implants for only 5 days, the bone cells reorganized to follow the implant thread pattern and resist the load. This unique bone pattern was observed only for 3 to 4 mm around the implants. Crestal bone loss was also noted around these implants and explained as stress overload.

Miyata placed crowns on integrated dental implants with no occlusal contacts (control group), and premature interceptive occlusal contacts of 100 microns, 180 microns, and 250 microns in a monkey animal model.[23-25] After only 4 weeks of premature occlusal loads, the implants were removed in a block section and evaluated. The crestal bone levels for 100 microns and control implants with no loading were similar. However, statistically significant crestal bone loss was observed in the 180 microns crown group and the 250 microns crown group experienced 2 to 3 times the bone loss of the crowns with moderate prematurities. Duyck used a dog model to evaluate the crestal bone loss around screw type dental implants with no loads (controls), static loads, and dynamic loads.[26] The dynamic loaded implants was the only group to demonstrate crestal bone loss. Since the only variables in these two reports was the intensity and type of occlusal load applied to the implants, these animal reports imply dynamic occlusal loading may be a factor in crestal bone loss around rigidly fixated dental implants.
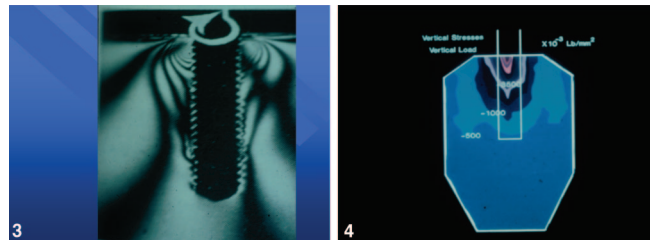

Fig. 3. Three-dimensional finite element analysis of an implant under load in a bone model demonstrates the highest strain patterns are around the crestal portion of an implant.
Fig. 4. An implant is threaded into a block of acrylic with a similar modulus of elasticity as cortical bone. A torque applied to the implant results with strain within the bone simulant material. The greatest strain levels are observed in the marginal areas next to the implant at the crest.
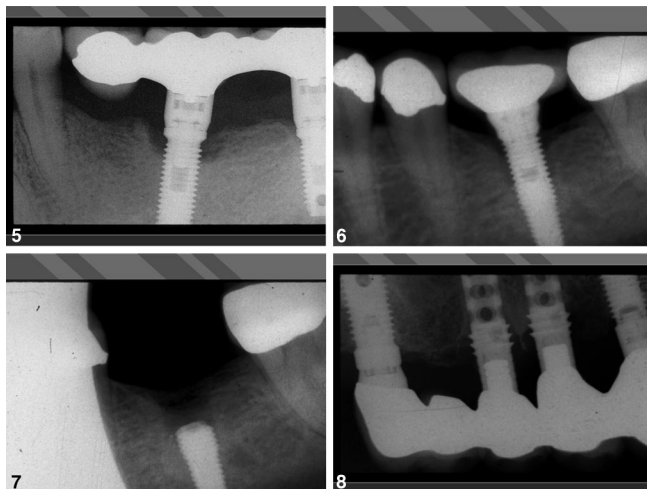
Fig. 5. This implant prosthesis has a cantilever to the mesial aspect. The implant nearest the cantilevers has marginal bone loss. Cantilevers increase the amount of force to the implants, especially the implant closest to the cantilever.

Fig. 6. Implant marginal bone loss is present around the first molar implant. The patient has a parafunctional habit.

Fig. 7. The implant body in Figure 6 fractured 2 months after the crestal bone loss was noted.

Fig. 8. An implant fixed prosthesis after 1 year of loading demonstrates radiographic marginal bone loss. The bone loss on the center two implants is similar. The bone loss on the far right implant is at the first thread and the bone loss on the HA coated implant to the distal is above the threads. Each implant design has a different bone level.

Clinical Reports

Clinical reports have shown an increase in marginal bone loss around implants closest to a cantilever used to restore the lost dentition (Fig. 5).[27-29] Cantilever length and an increase in occlusal stress to the nearest abutment are directly related,[30] and point to the fact that the increase in marginal bone loss may be related to occlusal stress. Quirynen et al evaluated 93 implant patients with various implant restorations and concluded that the amount of crestal bone loss was definitely associated with occlusal loading.[31] These authors also reported increased crestal bone loss around implants in patients with no anterior occlusal contacts and with parafunctional habits in full arch fixed prostheses in both jaws. These clinical reports do not provide statistical analyses to demonstrate a clear link between occlusal stress and bone loss. However, they indicate a consensus by some authors that occlusal overload may be related to the incidence of peri-implant bone loss around the cervical aspect of an implant. In fact, in a study of 589 consecutive implants Naert et al suggested overload from parafunctional

habits may be the most probable cause of implant loss and marginal bone loss after loading.[32]

Rangert et al have noted that occlusal loads on an implant may act as a bending moment that increases stress at the marginal bone level and can cause implant body fracture.[33] Prior to the fracture of the implant body, marginal bone loss was noted in this retrospective clinical evaluation (Figs. 6 and 7). The same stress which caused implant fracture is the logical cause of the peri-implant bone loss before the event. Rosenberg et al found microbial differences in implant failures from overload and those from biologic complications.[8] Urbine et al presented the case of a mandibular implant crown with a marginal peri-implantitis and osseous defect.[34] Histologic analysis revealed an infiltrate and a central zone of dense fibroconnective tissue with scanty number of inflammatory cells. According to the authors, this finding differs from chronic inflammatory tissue associated with infectious peri-implantitis and can be directly related to occlusal overload.

A clinical report by Leung et al, observed radiographic angular crestal bone loss to the 7th thread around one of two implants supporting a fixed

prosthesis in hyperocclusion 2 weeks after prosthesis delivery.[35] The prosthesis was removed and over the next few months, radiographic observation showed the crestal defect was restored to almost the initial level without any surgical or drug intervention. The prosthesis was then seated with proper occlusal adjustment. The bone levels stabilized at the second thread of the implant and remained stable over the next 36 months. This report indicates bone loss from occlusal overload is not only possible, but may even be reversible when found early in the process. Therefore, although no prospective clinical study to date has clearly demonstrated a direct relationship between stress and bone loss without implant failure, several practitioners agree a causal relationship may exist.

Implant Design Biomechanics

Different amounts of marginal bone loss have been reported for different implant body designs (Fig. 8). The design and surface condition of the implant body may affect the amount of strain distributed to an implant-bone interface.[36] A report by Zechner et al evaluated the peri-implant bone loss around functionally loaded screw-type implants with machined surfaced V-threads or a sandblasted/acid etched square thread design.[37] Four interforaminal implants were placed in the mandible in 36 patients and followed for 4 years. Over this period the average bone loss was 2.4 mm (V-thread) versus 1.6 mm (square thread). However, the range of bone loss in the study was 0.1 mm to 8.5 mm for machined V-threaded implants and 0.2 mm to 4.8 mm for rough-surfaced square threaded implants. There were 22 V-threaded implants that lost more than 4 mm of bone compared to 3 square threaded implants. Bone loss of less than 1 mm was reported for 16 rough surface square threaded implants compared to only 2 machined surfaced V-threaded implants. There were no clinical findings of inflammation or exudate. The range of bone loss with the different implant surface condition and design in a clinical report indicates that more than the biologic width, microgap position and/or surgical causes are involved in the individual implant mar-

ginal bone loss process. The other two most probable factors that influence the amount of crestal bone loss in this report are the amount of force applied to the prosthesis and the quality of the bone to resist these forces. All three of these factors (implant design, bone density, and magnitude of force) imply occlusal overload may be related to the amount of marginal bone loss around an implant.

A clinical report by Karousis et al also demonstrated that different implant designs and surface conditions correspond to different incidences of crestal bone loss.[38] Three different designed implants from the same manufacturer were evaluated over 10 years in a prospective report. One implant body design lost more than 5 mm of bone 26% of the time, while the other two designs reported 37% and 39% incidence. More than 6 mm of marginal bone loss occurred in 22% of the implants with the first design compared to 35% and 33% for the other two designs. This indicates one implant design may result in less marginal bone loss than another design, and points to the fact that clinical reports with similar healing and loading protocols, but of variable implant body designs and surface conditions, may yield different amounts of crestal bone loss. Since the implant design and surface condition affects the amount of stress transferred to the bone, one of the reasons for a bone loss difference between implant designs may be related to the stress transmitted to the bone.

In the field of orthopedics, hip joint replacement has encountered several complications including wound infection, periprosthetic fracture, dislocation, mechanical failure, and osteolysis.[39] Aseptic loosening of the bone-implant interface is the leading cause of late joint replacement failure and approximates 10% within 10 years (Fig. 9). Osteolysis refers to the bone resorption that occurs around both cemented and uncemented implants.[40] Mechanical loading factors are often associated with this condition.[41,42] Patient factors that increase loading failure include body weight and activity level.[42] An animal model and human report have linked the resorption of bone at the interface to
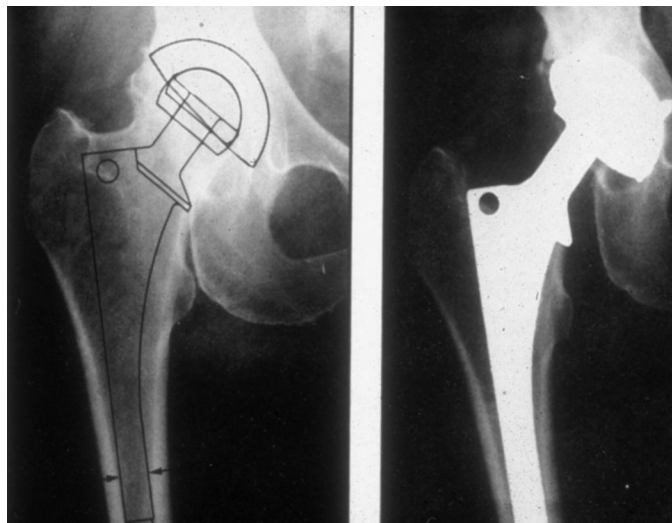

Fig. 9. Aseptic loosening of orthopedic hip joint replacement devices is caused primarily by mechanical loading factors.

mechanical overload.[43] Treatment of the disorder, if the patient is asymptomatic with a large osteolytic defect but no implant mobility, includes curettage of the osteolytic membrane and bone grafting.[44] Hence, these orthopedic reports accept the fact that mechanical overload can cause bone resorption at the bone-implant interface. The metal most often used in hip replacement therapy is titanium alloy and the bone implant interface is similar to a dental implant. In addition, the issues of bacteria contamination, microgap position, and microbial related bone loss are eliminated in this aseptic environment. It is logical to assume that these studies have significance in the relationship of dental implants and marginal bone loss from biomechanical stress.

DISCUSSION

The association of occlusal trauma and bone loss around natural teeth has been debated since Karolyi claimed a relationship in 1901.[45] A number of authors conclude that trauma from occlusion is a related factor in bone loss, although bacteria is a necessary agent.[46-51] On the other hand, Waerhaug and many others state there is no relationship between occlusal trauma and the degree of periodontal tissue breakdown.[52-54] According to Lindhe et al, "trauma" from occlusion cannot induce periodontal tissue breakdown.[55] However, occlusal

trauma may lead to tooth mobility, which can be transient or permanent. By extrapolation of this rationale, several authors have also concluded that occlusal trauma is not related to marginal bone loss around a dental implant.[5-7]

Limited marginal bone loss during the first year of function after stage II surgery has been observed around the perimucosal portion of dental implants for decades.[3,56] Hypotheses for the causes of crestal bone loss have included the reflection of the periosteum during surgery, preparation of the implant osteotomy, level of the microgap between the abutment and implant body, bacterial invasion, the establishment of a biological width, the implant crest module design, and occlusal overload.[2,57] For example, Jung et al and Wiskott and Belser found that marginal bone loss in the first 12 months of loading corresponded to the length of the polished collar of various implant designs.[58,59]

To this date no prospective human clinical trial regarding implant occlusion and crestal bone loss has been reported.[60] The fact that occlusal overload may be an etiology for crestal bone loss does not mean other factors are not present. For example, the microgap position of the implant platform and abutment and the biologic width often affect the marginal bone during the first month after the implant becomes perimucosal (Fig. 10).[43] Peri-implantitis may also have a role in this
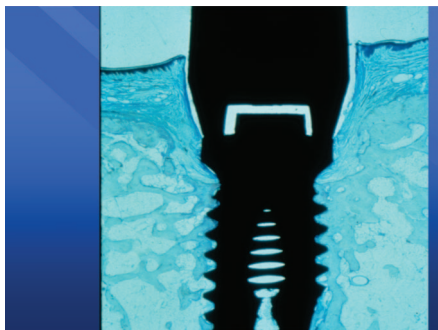
Fig. 10. The microgap position and the biologic width may cause marginal bone loss. For example, this implant (dog model) has no occlusal load and has marginal bone loss.

process, either early or late. It is not the intent of this paper to negate other possible causes of peri-implant bone loss. Instead this review is intended to gather data supporting a possible relationship between peri-implant bone loss and occlusal overload.

The clinician has certain variables under his/her control which may influence the amount of peri-implant bone loss. The position of the microgap in relation to the bony crest and the implant crest module design are primarily in the control of the implant surgeon. On the other hand, the autoimmune or bacterial response of the patient, the biologic width, and the patient response to the surgical trauma of implant placement are variables often escaping the control of the dentist. Once the final prosthesis is delivered to the patient, many factors that influence marginal bone loss have already occurred, while others such as occlusal overload and its relationship to the quality of bone continue to exist. Occlusal overload is one factor most in control of the restorative dentist. If a relationship between occlusal overload and crestal bone loss may exist, methods to decrease stress to an implant interface appear appropriate.

A puzzling element in the occlusal force to peri-implant bone loss relationship is the lack of continued bone loss until the implant fails. Implant crown height may be measured from the occlusal plane to the crest of the bone. The crown height is a vertical cantilever, which may magnify the stresses applied to the prosthesis. As a result of the greater crown height from the vertical bone loss, occlusal over-

load will be increased after crestal bone loss occurs. Therefore, if occlusal loading forces can cause crestal bone loss, the resulting increased moment forces should further promote the loss of bone until the implant fails. Yet, most clinical studies indicate the rate of bone loss decreases after the first year of loading and is minimal thereafter. For example, Adell *et al* observed during the first year of prosthesis loading an average of 1.2 mm bone loss measured from the first thread, whereas in subsequent years bone loss averages measured 0.05 mm per year.[3,56] There are several plausible explanations to this observation based upon bone physiology, bone biomechanics, and implant design.

Bone Physiology

The bone is less dense and weaker at stage 2 implant surgery than it is 1 year later after prosthetic loading.[61] Bone is 60% mineralized at 4 months and takes 52 weeks to complete its mineralization.[62] Partially mineralized bone is weaker than fully mineralized bone. In addition, the microscopic organization of bone progresses during the first year. Woven bone is unorganized and weaker than lamellar bone, which is organized and more mineralized. Lamellar bone develops several months after the woven bone has repaired and replaced the devitalized bone around the implant caused by the trauma of surgical insertion.[61] Hence, the occlusal stress levels may be high enough to cause woven bone microfracture or overload during the first year, but the increase in bone strength achieved after complete mineralization and organization may be able to resist the same stress levels during subsequent years.

As functional forces are placed on an implant, the surrounding bone can adapt to the stresses and increase its density, especially in the crestal half of the implant body during the first 6 months to 1 year of loading.[62] Piatelli *et al* reported in a histologic and histomorphometric study of bone reactions to unloaded and loaded non-submerged angled implants in monkeys that the bone changed from a fine trabecular pattern after initial healing to a more dense and coarse trabecular pattern after loading, especially in the

crestal half of the implant interface.[63] Hoshaw *et al* (in dogs) loaded threaded implants in dogs with a tensile load and noted that a fine trabecular bone pattern became coarse trabecular bone around the implant.[22]

Fine trabecular bone is less dense than coarse trabecular bone.[61] Since the density of bone is directly related to its strength and elastic modulus, the crestal bone strength and biomechanical mismatch between titanium and bone may improve in relation to the functional loading. In other words, the stresses applied to the peri-implant bone may be great enough to cause bone resorption during the first year, since bone strains are greatest at the crest. But the stress applied below the crest of bone is of less magnitude and may correspond to the physiologic strain, which allows the bone to gain density and strength. As a result, the occlusal load that causes bone loss initially (overload), is not great enough to cause continued bone loss once the bone matures and becomes more dense.

Implant Design Biomechanics

Implant design may change the amount or type of forces applied to the bone-implant interface. A smooth collar at the crest module may transmit shear forces to the bone.[36] Bone is strongest under compressive forces, 30% weaker under tensile loads, and 65% weaker to shear forces.[64] Hence, bone may heal to the smooth metal collar of the implant crest module from implant insertion to implant uncovery; but when under loading conditions, the weaker shear interface may be more inclined to overload the bone. The first thread of the implant is where the type of force changes from primarily shear to compressive and/or tensile loads. Therefore, in many situations the 35 to 65% increase in bone strength through changes from shear to compressive loads is sufficient to halt the bone loss process. This may be one of the reasons why implant designs with a 2 mm smooth collar above the first thread and a 4 mm smooth collar above the first thread, both lose bone to this "first thread" landmark.[60] A previous discussion reviewed the range of bone loss with different implant designs.[37,38] Since

implant crest module design may affect the amount of bone loss, and the implant design contributes to the force transfer of the bone/implant interface, the stress related theory for one of the etiologies of crestal bone loss is further enhanced.

SUMMARY

Literature from cellular biomechanics, engineering principles, differences in bone loss related to bone density, animal studies, and clinical reports all substantiate occlusal overload may be an etiology of peri-implant bone loss. Literature related to orthopedic joint replacement devices clearly indicates that biomechanical stress and overload contribute to bone loss at the implant interface. The increase in bone mineralization and organization during the first year, the increase in bone density at the implant interface, and the type of force changes at the first thread of the implant body are all factors that may halt the bone loss phenomenon after the initial marginal loss. Although this occlusal overload concept does not negate other factors related to marginal bone loss, the restorative dentist is most often able to impact this condition more than most or any other factors. Methods to decrease occlusal stress to the implant prosthesis are therefore warranted.

Disclosure

The authors claim to have no financial interest in any company or any of the products mentioned in this article.

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Medizinische Indikation für einen Zusammenhang zwischen okklusalem Trauma und Knochengewebsverlust im dem Implantat benachbarten Gewebe: ein Literaturbericht

ZUSAMMENFASSUNG: Für die Implantatgestützte Zahnheilkunde ist die Thematik einer möglichen Verbindung zwischen okklusaler Überlastung und Knochengewebsverlust im das Implantat umlagernden Gewebe nach wie vor nicht eindeutig geklärt. Ein Kausalzusammenhang zwischen dem Auftreten von Knochengewebsverlust im Randgebiet eines Implantats und okklusaler Überlastung würde für einen Behandlungsplan und ein Okklusalbehandlungsschema unter Einbeziehung eines Belastungsausgleichsansatzes sprechen. Das aus einer von Medline gestützten sowie handverlesenen Suche in der vergleichenden englischen Literatur sowie den thematisch zugehörigen Fachbüchern herausgefilterte Material wurde für eine selektive Prüfung der Artikel zu den Themen biomechanischer Stress und Knochengewebsverlust in der zellulären Biomechanik, technische Prinzipien, mechanische Eigenschaften des Knochengewebes, Tierversuche, klinische Berichte, Physiologie des Knochens sowie Biomechanik in der Implantaterstellung vorgenommen. Diese Unterlagen weisen nach, dass eine okklusale Überlastung der Implantate die Wahrscheinlichkeit eines marginalen Knochengewebsverlusts erhöhen kann.

SCHLÜSSELWÖRTER: Okklusion, ins Knochengewebe integrierte Implantate, Knochengewebsverlust im Kammbereich, marginaler Knochengewebsverlust, Knochenverlust im das Implantat umlagernden Gewebe

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Una correlación positiva entre el trauma oclusal y la pérdida de hueso periimplante: Apoyo de las publicaciones

ABSTRACTO: La relación entre la sobrecarga oclusal y la pérdida de hueso periimplante sigue siendo un tema controversial en la odontología de implantes. Una relación causal entre la incidencia de pérdida marginal de hueso al lado de un implante y la sobrecarga oclusal implica que un plan de tratamiento y esquema oclusal se beneficiarían de un método de gestión de la fuerza. Una búsqueda manual y con la asistencia de Medline de artículos en inglés evaluados por colegas y textos se usó para realizar una revisión selectiva de artículos relacionados con el estrés biomecánico y pérdida de hueso en la biomecánica celular, principios de ingeniería, propiedades mecánicas del hueso, estudios en animales, informes clínicos, fisiología del hueso y biomecánica del diseño del implante. Estos trabajos demuestran que la sobrecarga oclusal en los implantes podría aumentar la incidencia de la pérdida marginal del hueso.

PALABRAS CLAVES: oclusión, implantes endoóseos, pérdida crestal del hueso, pérdida marginal del hueso, pérdida del hueso periimplante.

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Uma Correlação Positiva Entre Trauma Oclusal e Perda Óssea Periimplante: Apoio na Literatura

RESUMO: O relacionamento entre a sobrecarga oclusal e a perda óssea do periimplante permanece um tópico controverso na odontologia de implantes. Um relacionamento causal entre a incidência de perda óssea marginal próxima de um implante e sobrecarga oclusal implica que um plano de tratamento e esquema oclusal se beneficiariam de uma abordagem de administração de força. Uma busca assistida por Medline e manual de literatura inglesa revisada por pares, e livros de texto relativos, foram usados para uma revisão seletiva de artigos aplicando tensão biomecânica e perda óssea em biomecânica celular, princípios de engenharia, propriedades mecânicas do osso, estudos animais, relatórios clínicos, fisiologia do osso e biomecânica do projeto de implante. Estes documentos demonstram que sobrecarga oclusal em implantes pode aumentar a incidência de perda óssea marginal.

PALAVRAS-CHAVE: oclusão, implantes endósseos, perda óssea da crista, perda óssea marginal, perda óssea periimplante.

Occlusal Traumaとインプラント周囲骨損失の直接的関係：文献による論証

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要約: Occlusal traumaとインプラント周囲骨損失の関係については、インプラント歯科学会内に賛否両論がある。インプラントに隣接する境界骨の損失とocclusal overloadの間に因果関係があれば、それはforce managementの考え方が治療計画と咬合管理に有益であることを示唆する。Medlineと足を使った捜索を利用して、細胞バイオメカニクスにおける生物機械的応力と骨損失、工学原理、骨の機械的性質、動物研究、臨床報告、骨生理学、インプラントデザイン工学の各議題に関してpeer reviewをすでに受けた英語文献と関連する教科書を選択的に調べた。これらの論文によって、インプラントへのocclusal overloadは隣接境界骨の損失を増大させうることがわかった。

キーワード: 咬合、骨内インプラント、crestal bone損失、marginal bone損失、peri-implant bone損失

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