Reasons for Marginal Bone Loss around Oral Implants

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ABSTRACT

Background: The reasons for long-term marginal bone loss around oral implants are not well understood.

Purpose: The aim of this paper is to analyze presented evidence behind anticipated reasons for long-term marginal bone loss around oral implants.

Materials and Methods: A computerized research was conducted on PubMed in April 2011 with the following keywords: oral implants and marginal bone resorption/crestal bone loss/bone loss/bone resorption. This search resulted in a total of one thousand one hundred ninety-four papers of which seven hundred fifty-three were clinical contributions. Further search and filtering finally resulted in 21 experimental studies and one hundred sixteen clinical studies, which were reviewed.

Results: No evidence was found that primary infection caused marginal bone resorption. Clinical papers that have reported high levels of peri-implantitis were not supported by data given. Clinical evidence was presented that the so-called combined factors (implant hardware, clinical handling, and patient characteristics) may lead to marginal bone resorption. However, once tissue damage has been caused by combined factors, inflammation and/or infection may develop secondarily and then result in peri-implantitis that may need particular clinical treatment.

Conclusions: As marginal bone loss primarily depends on numerous background factors, it seems logical that, for example, the use of poorly constructed implants placed and handled by untrained clinicians may result in high numbers of patients with secondary problems in form of peri-implantitis; having said this, control of combined factors may likewise lead to very good clinical results where peri-implantitis would represent a very rare disease indeed even at follow-up times of 10 years or more.

KEY WORDS: bone loss, clinical research, radiographs

INTRODUCTION

Marginal bone loss around oral implants may represent a threat to implant longevity. Therefore, criteria for implant success[1,2] early on identified the need of a steady-state situation with respect to marginal bone loss to call an implant successful. Whereas general consensus may have been achieved with respect to the importance of maintaining stable bone levels around oral implants, the actual reason for marginal bone loss remains highly controversial, infection or overloading the implants having been the main theories explaining marginal bone loss. The infection theory states that implants behave like teeth and are then susceptible to similar types of disease as teeth, the major difference being the term periodontitis reserved for teeth and peri-implantitis being reserved for implants. The overloading theory that has been presented as an alternative reason for marginal bone loss has, allegedly, received some support in individual cases where clinicians have altered bridgework/occlusion and with such procedures been able to stop further bone resorption around implants. Not surprisingly, the infection theory is supported mainly by periodontists, whereas the overloading theory is supported by many prosthodontists or restorative dentists (Figure 1). Another theory, if seldom quoted, explains

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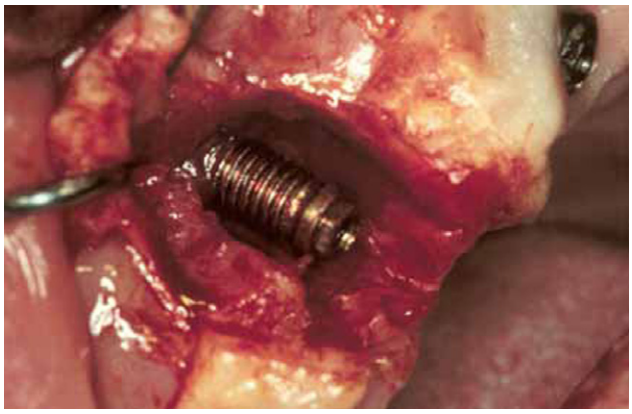

Figure 1 An implant with substantial bone resorption that started for unknown reasons.

marginal bone loss by the so-called combined factors,[3] including surgical, prosthodontic, and patient disorders. The conviction of supporting the "right theory" is extremely strong on all sides, exemplified by several consensus meetings on the problems with peri-implantitis[4] or suggestions to construct particular antimicrobial implant surfaces[5] on the one hand to using paper titles such as "On manufactured diseases, healthy mouths, and infected minds" on the other.[6]

Initial marginal bone loss, during the first year after implantation, may, according to the literature, be influenced by a number of parameters such as surgical trauma, occlusal overload, peri-implantitis, microgap, biologic width and implant crest module,[7] and flapless or flapped procedures,[8] but the focus of the present publication will not be the short term.

The aim of this paper is to analyze presented evidence behind suggested reasons for long-term marginal bone loss around oral implants. A computerized research was conducted on PubMed in April 2011 with the following key words: oral implants and marginal bone resorption/crestal bone loss/bone loss/bone resorption. This search resulted in a total of one thousand one hundred ninety-four papers of which seven hundred fifty-three were clinical contributions and the rest were either in vitro or other miscellaneous types of contributions. We, furthermore, used key words such as peri-implantitis and bone loss, and infection/inflammation, which resulted in 79 papers. The term overloading and implant bone loss or resorption/remodeling was entered which resulted in 46 papers. Platform switching (PSW) and marginal bone loss resulted in 49 papers, whereas smoking and oral implants and marginal bone loss resulted in 46 papers. Certainly, this list had many duplicates that were sorted out. In our final review, we decided to more carefully read 21 experimental studies and one hundred sixteen clinical studies based on reading head titles and, sometimes, abstracts of the respective papers. We strived for covering as many different aspects of and reasons for marginal bone loss as possible, which did influence our criteria for selecting individual papers. In addition, we have followed major journals such as *Journal of Clinical Periodontology*, *International Journal of Oral and Maxillofacial Implants*, *Clinical Oral Implants Research*, *Clinical Implant Dentistry and Related Research*, and *International Journal of Prosthodontics* to make it possible to add relevant data published after April of 2011. We have further read a particular volume of *European Journal of Oral Implantology* (supplement volume 5) as this was devoted to marginal bone maintenance of oral implants.

Our wide inclusion of different subheadings related to marginal bone loss made it difficult to introduce particular criteria for selecting papers in a proper systematic manner. Furthermore, to give an example, the PubMed search presented two hundred ninety-three papers on "ligatures and implants." By reading the titles of these papers, it was evident that only 58 of them were relevant for what is generally termed experimental induction of peri-implantitis. However, we see tissue destruction due to ligatures placed around implants as evidence for a typical foreign body reaction, similar in that aspect to cement particles accidentally found in the soft tissues after cementation of supraconstructions. Primarily, ligature reactions have nothing to do with the so-called peri-implantitis. Having said this, infection may arise in the long term, if secondarily, as foreign body disturbed tissues will present a locus of minor resistance.[9–11] As we find ligature studies to be quite irrelevant to primary peri-implantitis, we decided to only quote a few of the 58 available papers in our review. In this aspect, our review is a narrative one only. However, the basic search of papers was nevertheless done in a systematic manner; hence, this paper presents a combination of a systematic and a narrative review in that we personally made an evaluation of which subjects that we regarded being clinically important and, therefore, as in the example of ligatures, decided not to overburden our paper by going through 58 contributions of a rather peripheral experimental approach.

In addition, as our focus is on long-term reasons for marginal bone loss, we decided to disregard papers that only dealt with short-term (here defined as <1 year of follow-up) marginal bone loss.

Our primary aim has been to summarize the reported original reason behind marginal bone loss. In previous work from the Department of Biomaterials, we analyzed more than six hundred retrieved clinical oral implants[12] and found clear evidence in some cases of infection combined with marginal bone loss, which represents the definition of peri-implantitis as suggested by Albrektsson and Isidor.[13] However, such findings represent an end result when the clinician decided to trephine out the implant and need not necessarily prove that peri-implantitis was the original reason for onset of marginal bone loss. Therefore, we have decided to differentiate between *primary and secondary peri-implantitis*. Primary peri-implantitis is an applicable terminology when the infection is proven the original reason behind marginal bone loss, whereas secondary peri-implantitis may follow whatever original reason for marginal bone loss and possibly be related to other factors such as implant micromovements.

A recently published narrative review[14] logically came to the conclusion "when peri-implant tissue destruction occurs, little is known about the initiating process."

SUPPORT FOR INFECTION BEING THE DOMINANT REASON FOR MARGINAL BONE LOSS AROUND ORAL IMPLANTS

It is well known from the literature that bacterial colonization may occur around different types of implants, such as abdominal wall mesh devices,[15] orthopedic implants,[16] artificial breast implants,[17] and catheters.[18]

A consensus report presented that peri-implantitis is an infectious disease, which affects the supporting bone as well as the mucosa.[19] At first, mucositis occurs in the marginal part of the mucosal connective tissues as a response to bacterial conglomeration of the implant/crown. The bacteria allegedly responsible for marginal bone resorption may originate either from contamination during implant placement or on infection from the oral cavity afterwards.[20] It is well known that teeth may develop an infection-based disease called periodontitis. Many see tissue reactions to teeth and implants as identical which would speak for that peri-implantitis may develop around implants in a similar manner as periodontitis around teeth. However, interfacial arrangements differ between teeth that are anchored in a highly differentiated soft tissue, the periodontal ligament, and implants that if successful are anchored in bone tissue. The ligament has a rich supply of blood vessels and innervations in clear contrast to implants where the interface tissue has the blood supply typical for bone and lacks innervations or at least has minor innervations. In reality, it is highly questionable whether one may apply the same reasoning to the ligamental and bony interfaces, respectively.

A recently published systematic review[21] found "little support in the literature for a specific genotype or phenotype of immune reactivity that could be reliably used as an indicator of susceptibility to peri-implant disease."

Experimental Studies

Many animal reports of peri-implantitis are based on the so-called ligature studies. Ligatures are placed around experimental implants and then provoke an, allegedly, peri-implantitis like condition with marginal bone loss and infection/inflammation. Due to the great number of ligature studies, we have decided to select a sample of those in this review. Interesting as these studies may be, they are not presenting any clear evidence of peri-implantitis as the major reason for marginal bone loss in the clinical situation, even if some similarities between ligature-induced bone loss and clinical peri-implantitis have been reported.[22,23] The first authors to use the ligature model around experimental implants were Lindhe and colleagues[24] who pointed out that clinical and radiographic signs of tissue destruction were more pronounced at implants compared with teeth and that the ligature-induced lesion around implants extended into the bone marrow. Zitzmann and colleagues[25] reported inflammatory cells not only at mucosal sites but also extending to the peri-implant bone, and the authors reported progressive bone loss after ligature removal. Berglundh and colleagues[26] and Albouy and colleagues[27,28] performed a series of experiments with ligatures placed around different commercially available implants in a dog study. Albouy and colleagues[27–29] removed the ligatures and found that further bone loss did not occur with the so-called machined surfaces but continued spontaneously with commercially available implants such as

SLA (Straumann Co, Zürich, Switzerland), Osseospeed (Astra Tech, Dentsply, York, PA, USA), and TiUnite (Nobel Biocare AB, Zürich, Switzerland). After mechanical cleaning, they were able to stop further bone resorption around the two first mentioned implants, but not so for the third design, possibly dependent on small crypts in the latter design. These data are interesting, although they emanate only from experimental studies far away from the clinical reality. Furthermore, the results with more bone loss around the TiUnite design than the other commercially available implants are dependent on the chosen baseline that was ligature removal in the papers of Albouy and colleagues.[27–29] Had the time point of ligature placement been chosen instead, then there were no differences in marginal bone loss between the different implants.[30] The studies of Albouy and colleagues have been criticized for using incorrect statistics,[31,32] however strangely without giving rights for comments from the authors themselves.

The Microgap

One commonly incriminated reason for marginal bone loss is bacterial leakage from the microgap between implant and abutment.[33] Hermann and colleagues[34] performed an experimental study where they varied the placement of the microgap and reported that if the microgap was located at the level of the bone, more marginal bone resorption followed than if the microgap was located high up in the soft tissues. Hermann and colleagues[34] stated that the precise cause of the tissue changes was not known, but that one explanation was infection due to microgap leakage. Broggini and colleagues[35,36] confirmed these observations and found that the peak of inflammatory cells was found about 0.5 mm coronal to the microgap and consisted primarily of neutrophilic polymorphonuclear leukocytes. These studies may be compared with the clinical observation[37] that one type of hexed implants displayed more bone loss in the first year than did other implants with internal solutions that have no microgap in the bone region. However, it is then most interesting to observe that the hexed implants in the paper of Jimbo and Albrektsson[37] showed a very clear steady-state situation with respect to further bone loss after the first year. Hence, it is difficult to interpret the long-term importance of the microgap, if any, because the possibly infection caused early bone loss did not continue afterwards as may have been expected. There is indeed no evidence that implants with microgaps located at the bone level display less good clinical *long-term* results than implants without this location of the microgap. This lack of any long-term effects of the microgap is supported by Berglundh[38] who wrote ". . . long-term clinical data demonstrate stability regarding the marginal bone level irrespective of the presence of microbial leakage."

The Biological Width Concept

A certain minimal dimension of the peri-implant mucosa is required; hence, bone resorption may occur to allow a proper soft tissue attachment to form.[34,39–41] The bone resorption due to biological width establishment is, however, seen at early implantation times, that is, within the first year after implant placement,[42] and it is not a relevant factor for long-term marginal bone loss.

Clinical Studies

Hultin and colleagues[43] presented a clinical study that showed high levels of periodontal pathogens in implants with marginal bone loss in contrast to implants without marginal bone loss (Figure 2). Gualini and Berglundh[44] studied some immune histochemical features at implants and a higher proportion of B cells in peri-implantitis lesions than in mucositis lesions. Berglundh and colleagues[45] observed histopathological characteristics in six patients with 12 implants with progressive marginal bone loss and

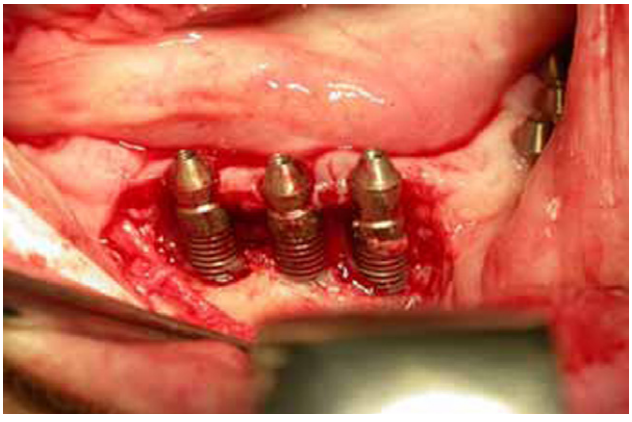

Figure 2 Implants like these may combine severe marginal bone loss with the finding of pathological bacteria around them. If so, this really says nothing about the original reason for the problem; we are looking at an end result of the three implants where a great number of different factors other than bacteria may have initiated the process of bone loss.

found numerous polymorphonuclear cells in different parts of the lesions. Renvert and colleagues[46] investigated two hundred thirteen patients with nine hundred seventy-six functioning implants and found no significant difference in the microbiota between implants diagnosed as "healthy" and those diagnosed as "peri-implantitis." Fransson and colleagues[47] investigated the clinical characteristics in 82 patients with peri-implant marginal bone loss and found pocket depth and pus in significantly greater amounts in implants with progressive loss of bone compared with those without such bone loss.

Roos-Jansåker and colleagues[48] and Fransson and colleagues[49] analyzed large clinical materials of patients with marginal bone loss of >1.8 mm or three threads and reported, respectively, 6.6 and 12.8% of implants to display peri-implantitis[48] or progressive bone loss.[49] The latter authors[49] defined progressive bone loss as any resorption after the first year of the implant if coupled with bleeding on probing and pus. The follow-up time in these studies was 9 to 14 years[43] and 5 to 20 years.[44] In the material of Roos-Jansåker and colleagues,[48] peri-implant marginal bone loss was found more commonly in patients with a history of periodontitis compared with patients without such a history.

Lekholm and colleagues[50] performed a clinical study where they reported that indications of gingivitis and deep pockets at the clinical examination were not found accompanied by an accelerated marginal bone loss or by a microflora or histological changes indicative of periodontitis. Åstrand and colleagues[51] reported only five implants out of one hundred twenty-three to display significant marginal bone loss in their 20-year investigation. Three of the five implants with marginal bone loss had clinical signs of inflammation, that is, peri-implantitis was diagnosed in 2.4% of the implants at 20 years of follow-up. Sundén-Pikner[52] reported that implants that displayed more marginal bone loss than others displayed the great proportion of this bone loss in the first 2 years after placement; thereafter, progress was generally slow. In addition, the author concluded that there was a cluster effect with respect to marginal bone resorption in that certain patients had a tendency of having several implants affected; the problem was not evenly spread in the patient group. The observation that the greatest marginal bone loss, should it occur, is seen rapidly after implant installation has been confirmed in other studies.[41,53,54]

Clinical Plaque Formation in Relation to Surface Roughness

Quirynen and colleagues[55] exchanged the abutment on clinically osseointegrated implants to a rougher type and reported that only minor differences in macroscopical plaque were noticed quantitatively and qualitatively even if rougher surfaces harbored more bacteria. Wennerberg and colleagues[56] performed a similar study without noticing any correlation between plaque formation and the roughness of the abutments. However, the authors[56] observed that there was a clear individual patient pattern in the amount of plaque formed on the implant. On the other hand, Baldi and colleagues[57] reported a greater plaque accumulation on dual acid etched compared with "machined" abutments. However, dual acid-etched surfaces displayed significantly less marginal bone resorption than machined ones.

PSW

"PSW is defined as a protocol that includes smaller diameter restorative components that have been placed onto larger diameter implant restorative platforms – the outer edge of the implant-abutment interface is horizontally repositioned inwardly and away from the outer edge of the implant platform"[58] (Figure 3). Although PSW was introduced as terminology by Gardner[59] and Lazzara and Porter,[58] the phenomenon was recognized earlier, even if the terminology PSW was not applied then. Chou and colleagues[60] reported a total bone loss of 1.500 oral implants at 3 years of follow-up to be 1 to 1.5 mm, regarded as a low level of bone loss and to depend on PSW. Other uncontrolled clinical data of PSW switched implants were reported by Wagenberg and Froum.[61]

Controlled studies by Canullo and colleagues[41] and Buser and colleagues[62] supported the notion that PSW implants displayed less marginal bone loss than non-PSW implants. The study by Canullo and colleagues[41] was of a randomized-controlled trial design and reported less marginal bone loss the greater the PSW over a follow-up to almost 3 years of observation. Buser and colleagues[62] found a mean crestal bone loss for PSW of 0.18 mm versus 2.18 mm when PSW was not applied.[63] These positive findings of PSW were supported in clinical studies by Hürzeler and colleagues,[64] Canullo and Rasperini,[65] Atieh and colleagues,[66] and de Almeida and colleagues.[67] In contrast, Enkling and colleagues[68] performed a randomized clinical trial to

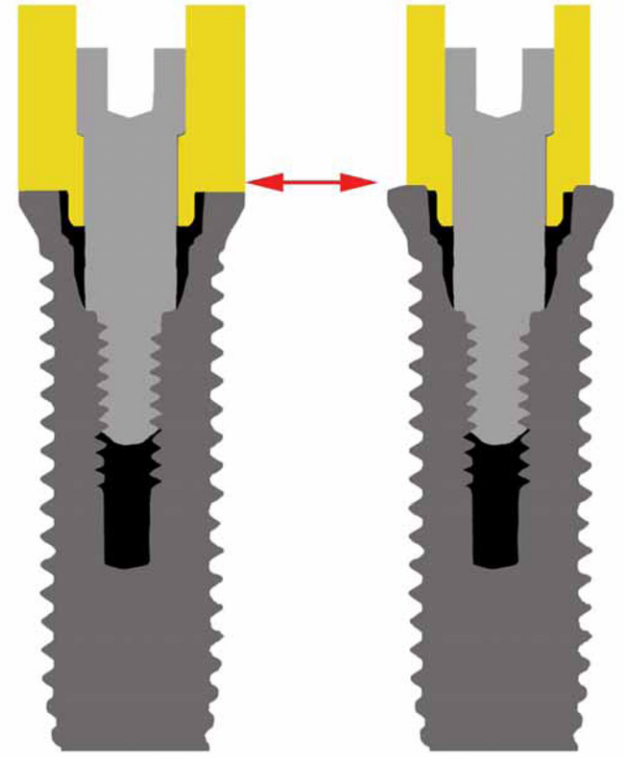

Figure 3 Platform switching means that "smaller diameter restorative components . . . are placed onto larger diameter implant restorative platforms"[58] and may end up in an improved marginal maintenance situation dependent on either imposed larger distance to the microgap or on the changed pattern of loading to more central parts of the implant. Courtesy of Michael Braian, published with permission.

evaluate the effect of PSW on peri-implant bone levels without being able to confirm the hypothesis of reduced peri-implant bone loss for platform-switched implants. Hsu and colleagues[69] and Vigolo and Givani[70] likewise saw no positive effects of PSW implants compared with non-PSW ones.

If there is an effect of PSW, this could be explained in different manners. One explanation would be infection orientated and relating to the implant-abutment interface being shifted inwardly, whereby the microgap cell infiltrate gets further away from the marginal bone or that the biological width is made adequate.[58] Another explanation of PSW minimizing bone resorption is biomechanical in that PSW implants display lower stress concentration than other implants without PSW.[71,72] A third possible explanation has been attributed to the great implant width seen with many PSW implants where modern implant surfaces have demonstrated very good clinical outcomes and minor bone resorption.[73–76]

THE EFFECTS OF SMOKING

Lindquist and colleagues[77] reported a 10-year cohort study that mandibular implants displayed only minor bone loss, but that smokers had greater bone resorption than nonsmokers. The increased bone resorption of smokers was supported in other studies by Haas and colleagues,[78] Carlsson and colleagues,[79] Nitzan and colleagues,[80] and Fransson and colleagues.[47] DeLuca and Zarb[81] presented a 20-year study of two hundred thirty-five patients with seven hundred sixty-seven Branemark implants and reported no difference in bone loss in the first year of clinical loading, but a higher incidence of marginal bone loss in the smoking group in subsequent years. Certainly, the negative effects of smoking may be used to support different theories behind marginal bone loss. However, smoking may indeed induce a great variety of oral manifestations of disease as reported by Sham and colleagues.[82] There are many irritants, toxins, and carcinogens found in smoke from tobacco; however, in addition, the mucosa may be dried by high intra-oral temperatures; and there may be pH changes, alterations in immune response or altered resistance to fungal or viral infections,[82] and reduced local blood supply to mention a few effects. It must be regarded as unknown whether the negative effects of smoking on marginal bone levels depend on local or systemic factors.

One very interesting paper reported that smoking was correlated to higher failure rate for turned but not so for moderately rough implants.[83]

SUPPORT FOR OVERLOADING BEING AN IMPORTANT REASON FOR MARGINAL BONE RESORPTION

Experimental Findings

Numerous experimental scientific papers support overloading as an incriminating reason behind increased marginal bone loss. Occlusal overload has been defined as the load that is greater than prostheses, implant components, or interface tissues, are capable of withstanding without damage.[84] Hoshaw and colleagues[85] investigated experimental dog implants and found a greater coronal bone loss in the loaded compared with the unloaded group. Isidor's classical study[86] demonstrated very clearly that overloading caused marginal bone loss in a monkey experimental model. Miyata and colleagues[87] reported a series of experiments on the effects of occlusal overload as well as the tissue response to

ligatures. Minor occlusal overload did not result in marginal bone loss if applied alone, but if ligatures were added, the summed bone loss was greater than would be expected with ligatures alone. This is an interesting observation as it presents the effects of combined trauma to the tissues. More substantial occlusal forces resulted in bone loss even without ligatures. Duyck and colleagues[88] reported that excessive dynamic overloading caused crater like bone defects in contrast to the statically or unloaded group. An animal experiment on the influence on the bone response of implants subjected to different types of loading reported higher cellular responses particularly in trabecular bone areas under nonaxial loading compared with the axially loaded group.[89] In contrast, Heitz-Mayfield and colleagues[90] found excessive occlusal load not to lead to more marginal bone loss than seen in the control group. Gotfredsen and colleagues[91] failed to find significant marginal bone loss as a response to static loads.

Clinical Findings

The frequent verbal reports of different prosthodontists that they can make marginal bone resorption stop only by changing the bridgework are without proper references and, therefore, so best ignored until properly reported. Quirynen and colleagues[92] presented a clinical study of 69 patients with fixed prostheses or overdentures followed up for 3 years and reported excessive marginal bone loss associated with parafunctional or postocclusion patients (Figure 4). Uribe and colleagues[93] placed single unit mandibular implants in the molar region and reported marginal bone loss 6 months after cementation, but saw very few inflammatory cells. Therefore, the authors attributed the bone loss to accidental occlusal overloading. Traini and colleagues[94] analyzed 10 loaded SLA implants and demonstrated a high strain level in the area associated with marginal bone loss. Heckmann and colleagues[95] performed an interesting long-term clinical study of 80 implants followed up for 10 years where they reported that stress and inflammation alone did not cause bone loss. However, with increasing inflammation score, a greater marginal bone loss was seen in the high stress group, an indication of the importance of combined factors for marginal bone resorption.

Other authors have failed in finding a correlation between occlusal wear and marginal bone loss.[96] Vigolo and Zaccaria[97] presented a 5-year clinical study and saw equivalent marginal bone levels in patients with or without visible signs of occlusal wear.

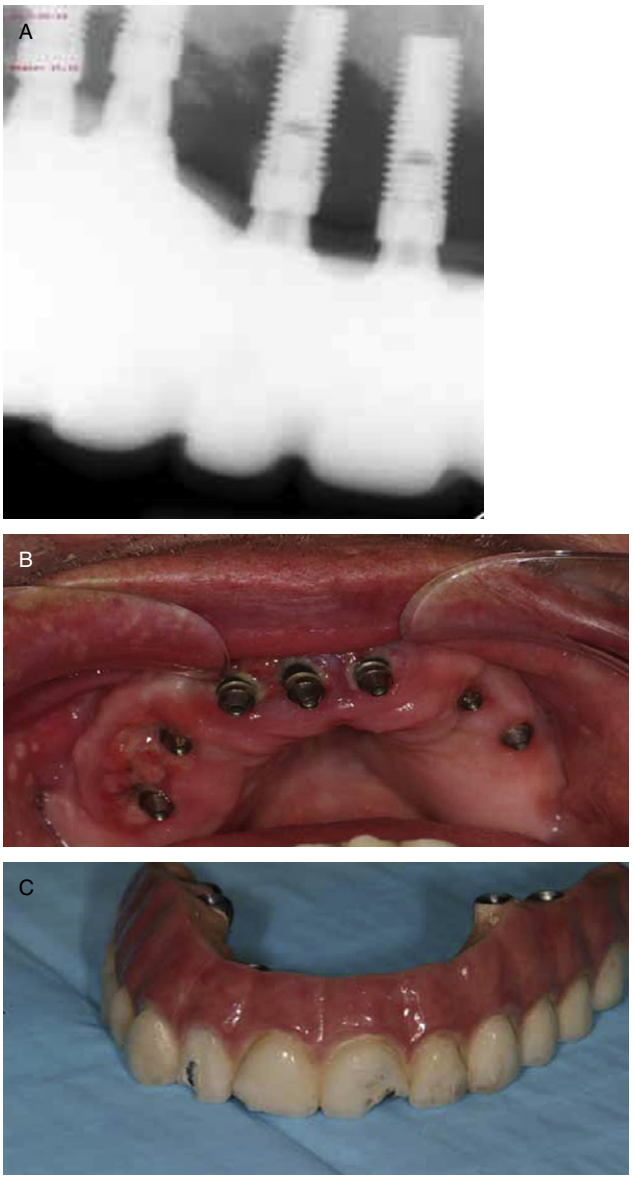

Figure 4 Clear signs of progressive marginal bone loss (A) with suppuration (B) representing one definition of peri-implantitis. However, in this case, both abutment screws were fractured and many clinical signs such as wear, chipping, and fracture of veneers (C) pointed to overloading problems in this bruxist patient.

Many experimental papers demonstrating marginal bone loss after overloading have been criticized for applying nonphysiological levels of load to prove the point. Hence, as with any experimental study, we do not know whether findings are clinically applicable. It is not that easy to translate experimental or clinical load levels to what is regarded the limiting factor for bone tissue that is strain, not stress. Bone adapts its mass and

structure to the loads to which it is exposed.[98,99] As pointed out by Halldin and colleagues,[100] the loads induce strains in the bone and the modeling/remodeling stimuli are dependent on strain magnitude, strain frequency, and strain rate.[101,102] Clinical studies finding more or less bone loss around cantilevered oral implants are, therefore, difficult to interpret scientifically as it is quite complicated to calculate the accurate strain levels in these cases. Our lack of knowledge with respect to the effect of overloading of implants is even more apparent if we consider the orthopedic perspective, where marginal bone loss around hips or knees is generally referred to as depending on stress shielding, that is, underloading instead of overloading the implant.[103] In a recent systematic review, Fu and colleagues[104] "concluded a positive correlation between occlusal overloading and peri-implant marginal bone loss."

COMBINED FACTORS BEHIND MARGINAL BONE LOSS

The Observation of Marginal Bone Loss Being Influenced by Certain Implant Designs

A great number of potentially osseointegrated oral implant systems have failed over the years and, therefore, disappeared from the market. One common failure mode is material brittleness leading to implant fracture seen, for example, with aluminum oxide implants. The other common mode of failure of oral implant systems is dependent on marginal bone resorption. Whereas successful oral implant systems have demonstrated average steady-state bone levels at least after the passage of the first year, many other systems have failed in so doing, which has lead to withdrawal from sales of the implant systems in question. The *Core Vent* hollow cylinder was very popular in the United States around 1990, allegedly with an American market share of about 35%. There was some evidence of Core Vent implants displaying a direct bone to implant contact in retrieved specimens from patients. The first clinical report of a consecutive number of 47 Core Vent titanium alloy cylinders with a reported success rate of only 9% was published in 1991.[105] The poor success rate was due mainly to an alarming level of bone resorption in this relatively short-term (up to 4 years) report. The Core Vent system has not been marketed since 1991. The *IMZ implant system* built on a solid, plasma sprayed cylinder design. This implant design demonstrated direct bone to implant contact and good survival rates for 5 years.[106] However, the IMZ never demonstrated average steady-state bone levels.[107–109] The ongoing bone resorption was, with time, so severe that implant failure rate increased; Haas and colleagues[110] reported only 13% success of IMZ maxillary implant followed up for more than 10 years. The IMZ system was withdrawn from marketing in 1997. The first generation of *Hydroxy-apatite (HA)-coated cylinder* implants again demonstrated initial osseointegration and quite acceptable early survival rates.[111] However, with time, an alarming bone resorption was reported[112–114] and this implant system was removed from the market by the end of the 1990s. The clinical catastrophe with alarming bone resorption seen around the bicortical screw resulted in disasters in Scandinavia.[115]

There is also evidence of bone maintaining design features. One such positive design contribution is *microthreads* that have been documented to help in maintaining bone levels around oral implants. Abrahamsson and Berglundh[116] found the marginal bone level to be located more coronally for implants with microthreads than for those without. This finding was supported by two controlled clinical studies,[117,118] although the latter authors only saw a statistical significance for implants placed in the maxilla.

Jemt and Albrektsson[119] concluded that "marginal bone loss at implants is a complex problem, caused by many different factors that are not yet fully understood. A single minded explanatory model for bone loss at implants is not acceptable" (Figure 5). This statement

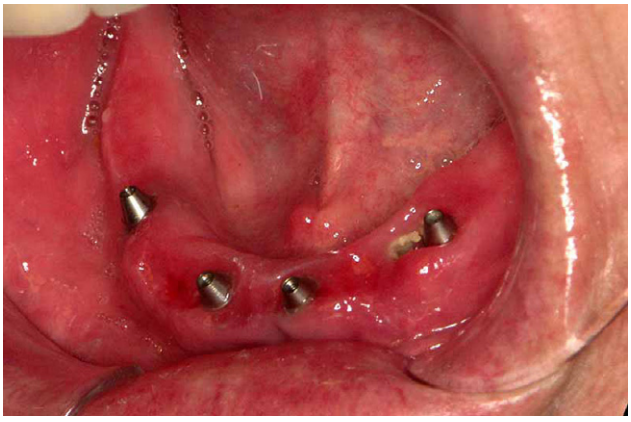

Figure 5 To minimize problems with marginal bone loss and inflammation/infection for the future, we need to look beyond what we see. This case has indeed these problems, but the case history includes a tumor that was irradiated and then, secondarily, peri-implantitis together with tissue necrosis developed.

can be seen against the background of these several failed implant systems that included implants with surface roughness ranging from very smooth to rough plasma sprayed devices and with designs ranging from hollow or solid cylinders to threaded screws. It is very unlikely to find one single reason for all these problems, evident not the least with a recent failure of an implant system: Nobel Direct.[120] This implant either showed failure or more than 3 mm of marginal bone loss at the short time of 18 months of follow-up.[121,122] An expert group of the Swedish correspondence to the Food and Drug Administration reported that there were substantial problems with marginal bone resorption around Nobel Direct, affecting (in different studies) between 14 and 55% of all placed implants.[123] However, a most interesting observation with the Nobel Direct was the finding that 68 of the five hundred fifty consecutively included implants that were placed conservatively displayed adequate clinical outcome with only minor signs of bone resorption and low failure rates. This was in sharp contrast to implants placed as recommended with grinding down of the fixture in situ combined with direct loading of it.[120] The grinding down of the implants resulted in undue vibrations and micromovements, not very good for an implant that is then loaded directly.[103] This is a very good example of combined factors, resulting in biologic challenge and marginal bone resorption (Figure 6).

Another interesting observation is made in clinical papers comparing moderately rough and smooth surfaces that showed no differences in clinical outcome if placed under normal conditions.[124] However, if patients smoked,[83] if implants were short,[124] if loading was direct,[125] or if other challenging factors were present,[126] then better clinical results were reported with moderately rough than smoother turned surfaces. This is another indication of the importance of combined factors in oral implantology; the normal situation when challenging situations did not exist presented good clinical results for nonoptimal turned implants, but if a challenging factors were added, the outcome was poorer compared with the situation with modern implants.

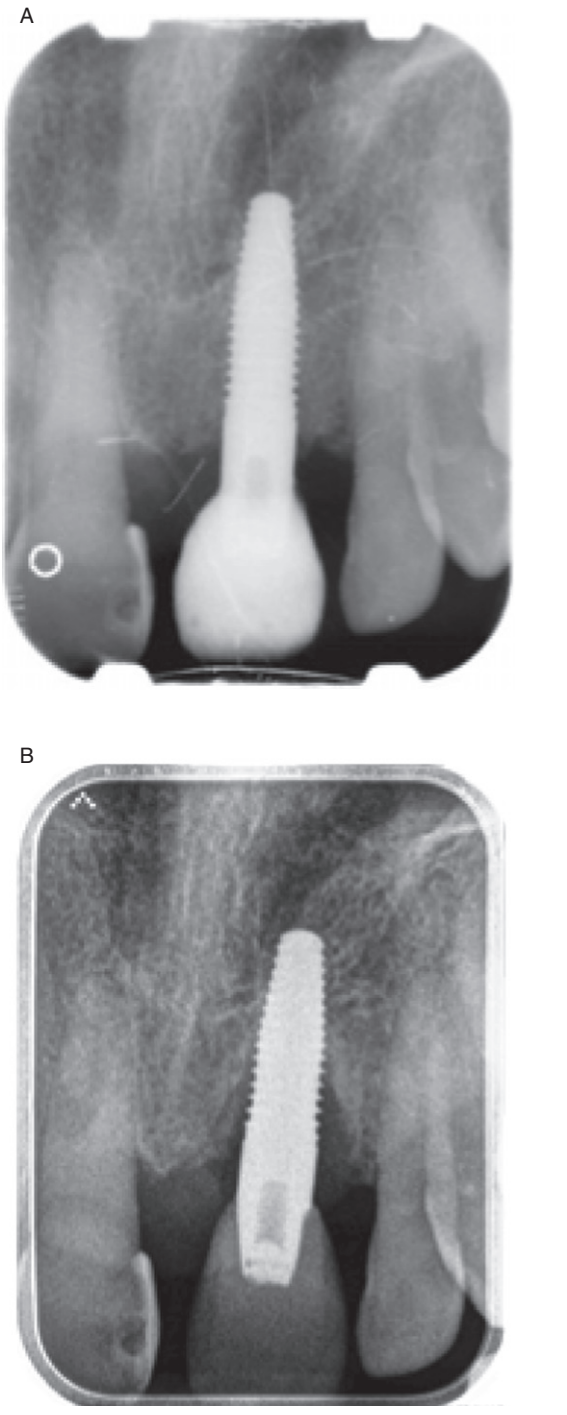

Figure 6 The importance of combined factors behind marginal bone loss was evident from the case of Nobel Direct, here a radiogram after placement of an implant (A). Substantial bone resorption or failure followed the recommended placement of these implants with grinding down of them in situ followed by direct loading in contrast to conservative placement of the same implants when results were good. Eight years after placement of the same implant (B).

The Observation of a Coupling between Clinical Handling and Bone Resorption

Bone sites of a poor bone quantity or quality are particularly sensitive to clinical handling: coupled factors. Nobody would recommend the clinical novice to start

working with implants in very difficult bone sites. The importance of the individual clinician is documented in a retrospective study that analyzed the outcome of all placed implants in 1986 at the Göteborg University dental school clinic and then coupled the outcome to the responsible surgeon who had placed the implant. One surgeon, with a couple of years of clinical experience, was alone responsible for 40% of the noticed implant failures as well as for a majority of the implants that demonstrated marginal bone loss. The same implant design was used by all 11 surgeons active there in 1986 when they placed close to one thousand implants.[127] Bryant[128,129] analyzed retrospectively one hundred thirty consecutive patients with the same implant design followed up for minimally 4 years and reported a correlation between marginal bone loss/implant outcome and the responsible surgeon, as well as correlation between marginal bone loss and the initial prosthodontist who took care of the patient.

Patient Factors in Relation to Marginal Bone Loss

Not only poor bone beds but also patient genetic disorders may relate to marginal bone resorption.[3] Another such patient factor is smoking (see separate heading) that may threaten implant outcome and show a correlation to marginal bone loss. Taken together, surgical and prosthodontic handling in combination with different patient disorders represent healing/adaptation factors behind marginal bone loss as described by Chvartszaid and colleagues.[3] If inappropriate implant designs are added as a risk factor, the healing adaptation theory comes close to the factors once described by Albrektsson and colleagues[130] to be responsible for maintaining osseointegration of oral implants. The healing adaptation theory is backed up by clinical documentation in some contrast to other primary reasons for marginal bone loss.

Excess Cement and Risks for Marginal Bone Loss

There is evidence that excess cement from cement-retained restorations may end up in the soft tissues of the patient and then result in localized swelling and marginal bone loss,[131–133] a not very surprising response to such tissue provocation. However, what is perhaps a bit surprising is the alleged reason for marginal bone loss being "infection."[131–133] "The most likely genesis of the problem is that this cement retains microbes" as suggested by one author,[125] whereas others suggested that soft tissue cement will "change the microflora to one that is consistent with periodontitis."[131] The described cases have, in general, showed uneventful healing if only the excess cement has been removed and the most likely cause of the problems with marginal bone loss in these cases would rather coincide with a foreign body reaction that may be quite aseptic and quite far away from supporting any infection theories.

COMMENTS ON MARGINAL BONE LOSS AND THE PREVENTION OF IT

Inflammation/infection in combination with marginal bone loss represents the definition for peri-implantitis as presented by Albrektsson and Isidor[13] and has been frequently reported as reason for implant removal.[12] However, whether peri-implantitis in such cases represents the original reason for implant problems or is mainly a secondary phenomenon, due, for example, to bone microfractures and/or implant micromovements, is unknown. This is the reason for our differentiating between primary and secondary peri-implantitis. For the patient already suffering from inflammation/infection and marginal bone loss, it may indeed be a semantic issue whether his disease is of a primary or secondary type. However, to minimize this problem in implant patients for the future, it would seem necessary to know precisely why marginal bone resorption develops. As is obvious from this review, there are many original reasons for marginal bone loss around oral implants, reasons not associated with any primary infection or overloading alone, but instead coupled with the used hardware, clinical handling, and different patient factors or dependent on foreign body reactions. With other words, to avoid or minimize marginal bone resorption, we would need the perfect implant handled by perfect surgeons and prosthodontists and placed in perfect patients with a good bone stock and no bruxism or smoking habits. Yet, some authors have pointed out that peri-implantitis is more common in patients with previous periodontitis[48] than in a cohort not previously suffering from periodontitis. If there is such a positive correlation between periodontitis and peri-implantitis, this does not prove the existence of primary peri-implantitis.

This review has suggested the importance of combined factors to develop marginal bone loss/secondary peri-implantitis.[3,83,95,120,124] We have found no reliable evidence of the existence of primary peri-implantitis alone causing marginal bone loss and very little, if any, evidence that overloading alone results in loss of marginal bone. Having said this, we cannot prove that primary peri-implantitis or overloading if acting alone never can cause marginal bone loss. Further clinical research in this area seems much needed. Proper control of combined factors is the probable reason for the excellent 10-year results of modern implants reported in a separate paper of this volume.[134]

CONCLUSIONS

1. There is clear clinical evidence that combined factors (implant hardware, clinical handling, and patient characteristics) may cause marginal bone loss or even failure of the implant.
2. It is possible that the mechanism behind the action of combined factors is bone microfractures or other types of bone injury that leads to inflammation that in turn triggers bone resorption.
3. In this review, we have found no evidence of a primarily infection-driven reason for marginal bone loss: peri-implantitis.
4. There is clinical evidence of a condition that may be termed secondary peri-implantitis; that is, other original reasons for marginal bone loss than infection (such as combined factors) may later make the implant harboring tissues more susceptible to infection that may further compromise the clinical situation.
5. With the data given, we cannot prove that overloading never can result in marginal bone loss around implants, but there is no evidence that overloading alone represents the incriminating factor behind marginal bone resorption around oral implants. Adverse interfacial strain may prove a better terminology than overloading as overloading is not an absolute but a relative term.
   a. Aseptic foreign body reactions (e.g., due to accumulation of cement particles in the soft tissues) may result in marginal bone loss and may further, due to combined factors, result in secondary peri-implantitis.

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