

Implant surface roughness and patient factors on long-term peri-implant bone loss

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Evolution in implant dentistry

Dental implants are widely used to restore function, aesthetic appearance and quality of life in partially and fully edentulous patients. Over 50 years of clinical scientific research have led to continuous improvement of dental implant designs, implant surface topography and a better understanding of bone and soft tissue biology. Compared with the era of the introduction of dental implants in clinical practice half a century ago, implant survival is today predictable, regardless of implant length, implant diameter, bone quality, available bone volume, surgical or prosthetic treatment protocol. The overwhelming positive acceptance of dental implants during the past decade has been lowered by suggestions of large incidences of biological complications that may only be clinically detected or become relevant after a sufficiently long time of follow-up. Suggestions have been made that implant surface topography may well have an impact on changes in peri-implant bone levels and consequently may affect the incidence of biological complications such as peri-implantitis.

Peri-implant bone level and peri-implant health

During the first European Workshop on Periodontology, opinion leaders from both academic and clinical backgrounds described the healing of dental implants and the diagnostic criteria for success, failure, health and disease. This included the classification of biological complications occurring in the tissues

surrounding dental implants. They defined mucositis as a local, plaque-related inflammation of the surrounding supracrestal mucosa and peri-implantitis as a localized inflammation that also yields irreversible crestal bone loss beyond the normal bone remodeling related to the initial healing process. It was well understood that the long term and predictable success of an implant was largely dependent on the crestal bone level preservation over time, logically assessed through radiographic assessment at regular time intervals. With the available implant surfaces at that time, this was described as not exceeding on average 0.2 mm yearly after the first year of function. De Bruyn and co-workers (22) reviewed the aspect of radiographic assessment of dental implants and suggested that mean bone loss may be useful in clinical research for comparison of implant systems or protocols, but yields very limited information on the condition of individual implants. Given the fact that a majority of implants yield very stable crestal bone levels over time with no bone loss at all, the statistical interpretation of mean values often hides the condition of implants positioned in the upper quartile of the bone level spectrum.

This was demonstrated by Pettersson & Sennerby (43) in a 5-year follow-up study including 88 patients treated with an anodized moderately rough surface implant. The cumulative survival was 99.6% and the average crestal bone loss from the day of implant placement to 5 years of function was 0.1 mm. However, widely spread and extreme values were reported and 15% of the implants showed more than 2 mm bone loss. Based on the cross-sectional evaluation at 5 years, it is tempting to suggest that these are at risk for peri-implantitis when applying, for

example, the criteria of the European Association for Osseointegration adopted in 2012 (35). However, in this particular study in total 24.6% of the implants already showed bone loss above 2 mm after the first year and after 5 years this bone level had not deteriorated but had even improved. This again demonstrates the risk when using cross-sectional assessment of bone levels as a surrogate for peri-implant disease in the absence of previous baseline registration. On the other hand, deep peri-implant pockets could very well be a clinical problem, despite bone stability. Fransson et al. (29) found that, at implant level, the presence of pus, soft tissue recession and a probing depth of 6 mm or more were statistically significantly more common around implants with radiographically identified progressive bone loss than around implants without such bone loss. Jemt et al. (31) reevaluated the patients from the latter study and showed that 69% of patients previously considered to have peri-implantitis demonstrated little or no problems with their implants during the follow-up period of 9 years. Only 3.1% of implants were lost and there was no statistically significant difference in bone loss between 'affected' and 'non-affected' implants. A total of 91.4% of the implants that were followed had no or less than 0.2 mm annual bone loss. A recent consensus summary indicated that indeed the majority of implants display an equilibrium in bone level stability and fortunately rarely show progressive bone loss when being used by properly trained clinicians (4, 5).

The large biological range seen in peri-implant bone loss was confirmed by Vervaeke et al. (52) in a prospective clinical 9-year follow-up study of 39 patients with full arch, screw-retained restorations on 5–8 TiOblast surface implants (Astra Tech, Mölndal, Sweden). The survival rate was 99.2% and the total mean bone loss from implant placement to 1, 3 and 9 years was 0.68 mm, 0.86 mm and 1.68 mm, respectively, indicative of an average ongoing, yet acceptable bone loss when applying the old criteria for implant success. In this particular study, 30% of all individual implants lost more than 2 mm after 9 years. This was explained by smoking combined with a history of periodontal disease. The estimated bone loss was 1.2 mm higher for smokers compared with non-smokers and 1.2 mm higher for patients with a history of periodontal disease compared with periodontally healthy patients. When both factors were combined the extra bone loss was calculated as 2.4 mm. Doornewaard et al. (26) concluded in a recent meta-analysis that implants placed in patients with

a periodontal history and with smoking habits yielded more bone loss. This points clearly to the effect of the patient population when discussing bone loss as a surrogate for peri-implantitis and stresses the importance of controlling confounding factors such as different patient-related risk factors in order to understand the large variability of bone loss measurements in scientific papers.

Unfortunately, many clinical papers do not report detailed information of bone loss or peri-implant health with respect to different patient groups or do not use multivariate statistical analyses in order to control for confounding. Even systematic reviews, including meta-analyses, tend to narrow the research question to such an extent that various factors are indeed overlooked. Especially the large variation in implant design, implant surface and type of prosthetic connection is often overlooked when assessing peri-implant bone loss in relation to certain patient factors.

Implant surface modifications

The two dental implant systems launched in the 1980s and 1990s had two distinctive surface topographies: the machined minimally rough Brånemark implant system (Nobelpharma, Gotenburg, Sweden) developed in Sweden (3) and the rough microporous Titanium Plasma Sprayed (Straumann, Basel, Switzerland) implants developed in Switzerland (48). Up to 20 years' implant survival rates with Brånemark system implants in the range 80–95% have been reported in fully edentulous jaws (8, 9, 27, 38) and over 91.5% for single tooth replacements (24). Chappuis et al. (14) reported in a prospective study a 89.5% survival of titanium plasma sprayed implants after 20 years of function in partially edentulous cases. In the latter study fewer than 15% of the implants were additionally subjected to some treatable biological problems and classified as surviving, but not successful. As reviewed by Wennerberg & Albrektsson (54) the currently available implant systems from the major implant manufacturers differ from their respective predecessors in micro-roughness, physicochemical properties and nano-roughness. The purpose of surface modification of implant surfaces is to positively affect the host-to-implant tissue response (20). The modification methods can be divided into subtractive and additive processes (53). Basically, the subtractive methods remove material from the implant surface, whereas the additive methods add material.

One of the most common subtractive methods is blasting. This is commonly done by blasting ceramic particles, such as alumina, titanium oxide, calcium phosphate or sand, onto the implant surface through a nozzle at high speed using compressed air (37). Material is removed from the surface, creating pits. However, blasting may leave remnants of the blasting material on the implant surface, which may have an effect on the clinical performance of the implant (6). Etching is another subtractive method, often used in combination with blasting. Etching agents such as HCl, H₂SO₄, HNO₃ and HF are used (37). This process aims at smoothing out some peaks in the microstructure and adding a high-frequency component of the surface in order to aid protein adhesion, facilitating bone formation as well as removing processing by-products (20). Oxidation is yet another subtractive method for the surface modification of titanium implants. Anodic oxidation can change smooth titanium surfaces into nano- and micropores as well as both thickening and changing the crystallinity of the oxide layer. Typically, strong acids such as H₂SO₄, H₃PO₄, HNO₃ and HF are used during an anodic oxidation process (37). Titanium plasma spraying is an example of an additive process. This entails injecting titanium particles into a torch at high temperature. The particles will then fuse, creating a film on the implant surface, increasing the surface area (37).

Surface roughness is often described in terms of R_a which is a two-dimensional parameter, or preferably S_a , the corresponding three-dimensional parameter, which describe the height of the surface structure, i.e. the mean arithmetic deviation of a profile (53). Dental implant surfaces are classified into four different groups, according to their surface roughness. Smooth implant surfaces refer to an S_a value of less than 0.5 μm ; minimally rough surfaces refer to S_a values of 0.5 to less than 1.0 μm ; moderately rough surfaces refer to S_a values between 1.0–2.0 μm ; and finally, rough surfaces have an S_a value of more than 2.0 μm (6). Smooth surfaces are not clinically available, but used experimentally. Machined Brånemark, Osseotite and Nanotite implants are examples of minimally rough implants. Illustrations of moderately rough implants include SLA, TiUnite, OsseoSpeed, TiOblast and the Southern Implants, whereas IMZ, TPS, Ankylos, Friadent and Xive represent rough surfaces. Table 1 gives an overview of implant surface roughness of major brand names of dental implants.

Surface modifications and clinical outcome

By and large, implant surface modifications have led to stronger bone responses, which may explain the high implant survival, and have also allowed predictable treatment in multiple treatment indications and more challenging conditions such as immediate placement (42) and immediate loading (22, 47, 51, 52). When it comes to the aspect of bone loss around implants with different surface texture, a consensus meeting of the European Federation of Periodontology scrutinized the available scientific evidence in 2008. It was stated that there was scarce information and only short-term studies not exceeding 3 years follow-up available at that time. Nevertheless, it was acknowledged that surface modified implants lead to the preservation of marginal bone without any clinically significant superiority for any particular implant surface or design (36).

Another systematic review (32) scrutinized 71 articles reporting on bone loss after at least 5 years of follow-up. Clinical implant survival was attributed to the implant surface. Maxillary moderately rough implants were found to have significantly higher long-term survival rates than maxillary minimally rough implants but this difference was not observed in the mandible. Marginal bone loss occurred around all the implants in the first year but stabilized thereafter, indicating the absence of progressive bone loss. A comparison of implant systems with different implant topography revealed that some implants were associated with statistically significantly greater mean marginal bone loss, mainly seen during the initial bone remodeling phase. TiOblast and SLA surface implants yielded less marginal bone loss than turned surfaces or TiUnite surface implants. However, all implant systems demonstrated no further progressive bone loss from the end of year 1 to year 5, indicative of stable peri-implant bone levels and low peri-implantitis incidence. A review summarizing 10 papers reporting on the 10 year clinical outcome with surface modified implants treated by sandblasting, grit blasting, acid-etching or combined treatments, revealed that the survival was above 95%. Furthermore, fewer than 5% were diagnosed with purulent infection or peri-implantitis (5). One should keep in mind that these excellent results were often realized in academic development centers with often very strict inclusion criteria regarding patient selection and with treatment protocols performed by highly qualified surgeons and prosthodontists.

Table 1. Implant surface roughness (S_a value and degree of roughness) and surface treatment of the specific implant brands and implant systems

	S_a value	Degree of roughness	Gritblasted	Etched	Plasma sprayed	Electrochemically oxidized
Straumann TPS	> 2.0 μm	Rough			x	
Straumann SLA	1.78 μm^*	Moderately rough	x	x		
Straumann SLActive	1.75 μm^*	Moderately rough	x			
Astra Tech TiOblast	1.1 μm^*	Moderately rough	x			
Astra Tech Osseospeed	1.4 μm^*	Moderately rough	x	x		
Dentsply: Ankylos/ Friadent/Xive/ Frialit	> 2.0 μm	Rough	x	x		
Nobel Biocare: TiUnite	1.1 μm^*	Moderately rough				x
Zimmer TSV MTX	Unknown	Unknown	x			
Zimmer TSV MP-1 HA	> 2.0 μm	Rough	x			
Camlog	> 1.1–2.0 μm	Moderately rough	x	x		
SPS Endopore	> 2.0 μm	Rough				
Biomet Prevail (Ti-6Al-4V)	0.3 μm^*	Smooth		x		
Biomet3i Osseotite	0.68 μm^*	Minimally rough		x		
Biomet3i Nanotite	0.5 μm^*	Minimally rough		x		
Machined Brånemark system	0.9 μm^*	Minimally rough				
Calcitek	> 2.0 μm	Rough			x	
IMZ	> 2.0 μm	Rough			x	
Leone	> 2.0 μm	Rough	x		x	

*According to Wennerberg and Albrektsson (54).

Doornewaard and collaborators (26) performed a systematic review including papers with at least 5 year follow-up to assess the effect of implant surface topography on long-term peri-implant bone stability. They classified the implants described in 87 clinical reports according to surface roughness from minimally rough, moderately rough or rough using the known S_a value. The average weighted implant survival rate was 97.3% after 5 years or more of

loading for the total material and 96.4% for rough, 98.4% for moderately rough and 97.6% for minimally rough. Figure 1 summarizes the implant survival rate and corresponding function time for the three surface roughness groups and a mixed non-specified surface group. In 44% of the studies the implant survival rate was 95–100%, in half of the studies the survival was 90–95%. Only in 6% of the studies was the survival below 90%, with 73.4% survival after 20 years the

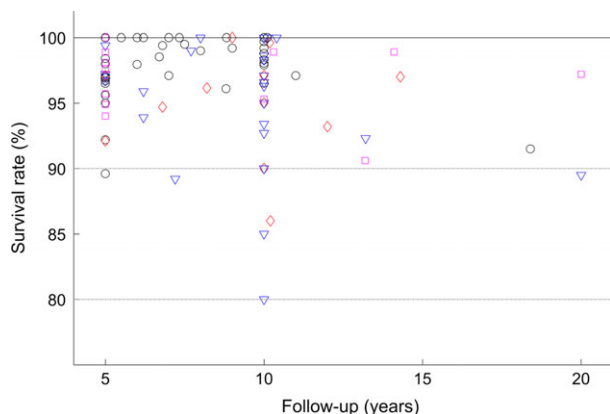


Fig. 1. Implant survival in relation to loading time and surface roughness for rough ∇ , moderately rough $\circ$, minimally rough $\diamond$ or unknown surfaces $\square$. According to Doornewaard et al. (26).

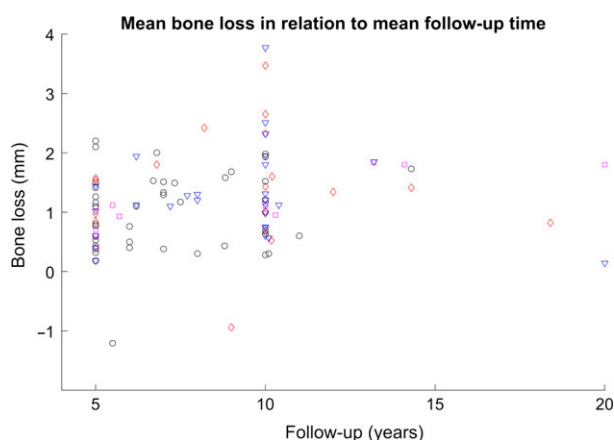


Fig. 2. Mean bone loss (expressed as positive value in mm) in relation to loading time and rough ∇ , moderately rough $\circ$, minimally rough $\diamond$ or unknown surfaces $\square$. According to Doornewaard et al. (26).

lowest being with a porous titanium alloy implant having a rough surface (23). Figure 2 summarizes the peri-implant bone loss in relation to the degree of implant roughness. The outcome of this review suggests that peri-implant bone loss around minimally rough implant systems was statistically significantly less (0.86 mm) in comparison with the moderately rough (1.01 mm) and rough implant (1.04 mm). For each study the mean bone loss was used together with the number of implants to calculate the weight of the study in the overall statistical analysis and to estimate the proportion of implants with bone loss above 1, 2 and 3 mm. For minimally, moderately or rough implants the proportion of implants with more than 2 mm bone loss was 14, 18, 20% respectively, again indicative of less bone loss with smoother surfaces. No statistically significant difference was observed between moderately rough and rough

implant systems. The few studies that do compare implants with comparable design and different surface roughness, showed less average peri-implant bone loss around the less rough surfaces in the meta-analysis. If considering 3 mm bone loss after at least 5 years to represent the presence of 'peri-implantitis', 3–5% of the implants were affected with a better result for smoother surfaces. The authors therefore concluded that the systematic review and meta-analysis of published long-term follow-up studies on dental implants show statistical differences among surfaces, albeit with minimal clinical significance (26).

A drawback in all these analyses is the fact that implants do not only differ in surface topography but also in implant design, prosthetic connection and loading protocol, let alone that the baseline for bone loss calculation is often non-standardized. Hence, it is difficult to conclude to what extent surface topography alone is responsible for the encountered bone loss. Recently Vandeweghe and coworkers (51) evaluated up to 21 years follow-up of implants (Southern Implants, Irene, South Africa) with similar macroscopic implant designs but with either smooth or moderately rough implant surfaces. The overall implant survival after an average 14 years was 97%. Multivariate statistical analysis revealed that the rougher surface implants showed more crestal bone loss compared with the smoother ones. With an arbitrarily chosen bone loss of 2.4 mm taken as the threshold for peri-implant disease, 25% of the rough surfaces versus 10% of the smooth surfaces were considered at risk. However, when applying the criteria to diagnose peri-implantitis according to Berglund et al. (10) and combining probing depth, bleeding and bone loss, only 4.1% of the implants overall yielded peri-implantitis without any difference between the two surfaces. Browaeys et al. (11) evaluated smooth Osseotite surface implants (Biomet3i, Palm Beach, USA) placed in fully edentulous jaws in conjunction with immediate loading either in healed or grafted bone. The overall survival of the implants was 91% after an average of 7 years. Studies using anodized roughened TiUnite implants (Nobel Biocare, Zurich, Switzerland) showed an implant survival of 97% and 0.7 mm bone loss after 9–12 years (41), Ostman et al. (42). Buser and co-workers (12) reported 98.8% survival of sandblasted and acid-etched SLA implants (Straumann, Basel, Switzerland) and minimal bone loss after 10 years.

In 2012, at the Estepona Consensus conference (4), it was concluded that peri-implant bone loss may be affected by several implant-, clinician- and

patient-related factors as well as foreign body reactions. Implant factors include: material, surface properties and design (e.g. ease of plaque removal); clinician factors include: surgical and prosthodontic experience skills and ethics; patient factors include: systemic disease and medication, oral disease (e.g. untreated or refractory periodontal disease, local infections), behavior (e.g. patient compliance with oral hygiene and maintenance, smoking) and site-related factors (e.g. bone volume and density, soft tissue quality); and foreign body reactions (e.g. corrosion by-products, excess cement in soft tissues). These suggestions have recently been evaluated by means of a number of systematic reviews including meta-analysis whenever possible.

Patient related factors and clinical outcome

A number of recently performed systematic reviews have tried to explain implant loss, peri-implant bone loss as well as peri-implant infections in relation to the number of patients, implants and treatment factors. Chrcanovic et al. (15, 17, 18) described patient-related risk factors, including smoking habits, history of periodontal disease and diabetes in a series of systematic reviews including meta-analysis. Smoking habits were suggested to affect implant failure rates, the risk of postoperative infection and marginal bone loss around implants. They explained the increase of implant failure rates by the effect of smoking on osteogenesis and angiogenesis. Moreover, nicotine was identified as an influential factor in the regulation of osteoblast proliferation, differentiation and apoptosis, leading to an aberrant effect on bone formation and remodeling (40). Furthermore, it was demonstrated that smoking had a significant impact on the survival of implants inserted in the maxilla. In contrast, no statistical significance could be identified for the mandible, possibly due to the limited number of studies (18, 39). Finally, Chrcanovic et al. (18) concluded that smoking was also associated with an increased number of failures, irrespective of implant surface type. In a recent systematic review (49) smoking and diabetes were suggested as biological associated factors for peri-implantitis although with a limited body of evidence. The specific contribution of general health problems to peri-implantitis requires additional robust epidemiological and clinical investigations. The history of periodontal disease was suggested as a second patient-related factor (52). It

has been demonstrated that patients with a previous history of periodontitis are prone to lose teeth. Consequently, they portray a higher need for implant therapy as opposed to periodontally healthy patients. In the latter group, rehabilitation with dental implants is generally caused by trauma or tooth agenesis (30). Chrcanovic et al. (17) concluded that an increased susceptibility for periodontitis may also translate into an increased susceptibility for implant loss, loss of supporting bone and/or postoperative infection. No significant relation could be identified between diabetes and implant failure, as no differences were observed between patients with and without diabetes (15). Additional to patient-related factors, surgical-related factors have also been investigated, including the angulation of implants and the moment of loading (1). Chrcanovic et al. (19) concluded that the insertion of dental implants in a tilted position compared with axially placed implants, did not statistically affect the implant failure rates. As concluded in multiple articles (16) the difference in occlusal loading between immediate non-functional and immediate functional loading may not affect the survival of these implants and no significant effect on the marginal bone loss has been reported. All these reports make clear that bone loss is multifactorial in nature and hence that peri-implant health is a consequence of many factors, among others the implant-related ones.

Surface modifications and peri-implantitis

Despite the proven clinical benefit of the currently available, surface-modified implants, some scientific reports suggest that surface roughness may play a decisive role in the development of peri-implantitis, the latter defined as inflammation in the mucosa and loss of supporting bone (55). Polizzi and co-workers (44) retrospectively compared minimally rough machined Brånemark implants with moderately rough TiUnite implants. After 10 years there was a cumulative survival rate of 90.3% and 96.6%, respectively, clearly demonstrating that the clinical survival improved significantly with the rougher implant. There was no statistical difference in bone loss between both surfaces, but peri-implantitis was seen in 2% of the implants whereby the proportion was 9/1 for TiUnite/Machined. Also some laboratory, animal or 'proof of principle' studies have suggested that surface roughness may play a role in disease

development. Amongst others as an example, John et al. (33) performed an initial biofilm growing experiment on four titanium discs with different surface textures or chemical modifications. After 48 hours of intra-oral contact the specimens were evaluated. It was concluded that machined-surface discs were showing a slower biofilm formation and slower plaque maturation and a higher affinity to fibroblast growth than the roughened acid etched or sand-blasted surfaces. It was speculated that this could have an effect during initial healing or even during oral hygiene measures because plaque would be initially retarded and easily removed. This conclusion seems, however, hard to sustain in the context of peri-implantitis, which is known to develop slowly and is of a multifactorial nature. Also, it has not been proven that this finding is of clinical relevance once an implant surface is exposed to long-standing biofilm formation.

Other studies refer to animal experiments whereby so-called experimental peri-implantitis is initiated around implants of various surface textures and different designs by ligature placement and extreme plaque accumulating conditions. Some experiments of this nature have shown that bone defects are larger at implants with a modified surface than at implants with a smooth, turned surface (13). Histological analysis revealed that peri-implantitis sites exhibited inflammatory cell infiltrates that were larger, extended closer to the bone crest and contained larger proportions of neutrophil granulocytes and osteoclasts than in artificially induced periodontitis around natural teeth. Furthermore, it was suggested that implant surface characteristics influence the inflammatory process and the magnitude of the resulting tissue destruction. Another experiment of similar design initiated peri-implant bone destruction on four different implant systems with turned or rougher surface textures and tried to treat the created bone defects with flap surgery similar to the treatment of periodontal disease. It was concluded that resolution of the defects was possible but not to the same extent on all types of surfaces (2).

It is known that implant surface properties may affect initial biofilm formation because of differences in surface free energy and surface roughness. Especially for abutment surfaces this aspect can be of clinical relevance since these components pierce the soft tissue barrier (45). Whether the surface of the implants is of influence for long-term bone stability or peri-implant health under clinical conditions in humans remains uncertain and some of the evidence seems contradictory. In a Cochrane Collaboration

review from 2003 (28), including many implant surfaces that are currently not predominant on the market any longer, it was concluded that there were no statistically significant differences for failures, radiographically assessed marginal bone loss and peri-implantitis between various implant systems. Some recent studies report lower bone loss with rougher surfaces than with smooth ones (7, 47), whereas others report less bone loss with smoother implant surfaces in the long run (34, 51).

The major implant brands compete to achieve the lowest bone loss over time, whereby often minute statistical differences prevail over real life clinical significance. In a 13-year follow-up study bone loss and incidence of peri-implantitis, the latter defined as bone loss above 1 mm and bleeding on probing or suppuration, was similar between Astra Tech TiOblast and Nobel Biocare TiUnite implants. The overall bone loss during the first 7 years after implant installation was greater than thereafter and the predictive value of microbiological biofilm composition for peri-implantitis incidence at 13 years was poor (46). A similar outcome was reported in a microbiologic assessment of submucosal flora around Astra Tech TiOblast and Machined surface Brånemark implants after 12 years of function. It was concluded that both implant systems, having differences in macro-design and surface characteristics, maintained a successful treatment outcome without significant subgingival microbiological differences after 12 years of loading. Furthermore, the presence of periodontal pathogens did not necessarily result in bone loss (50), a finding also confirmed by Dierens et al. (25). They assessed microbial composition of the peri-implant sulcus around smooth surface Brånemark single implants after 16–22 years of function. Although periodontal pathogenic bacteria were present even in high numbers, the majority of implants presented with healthy peri-implant tissues and no progressive bone loss, questioning the applicability of bacterial testing as a diagnostic tool for peri-implantitis. A lack of association between bacterial composition of the submucosal biofilm and bone loss was also confirmed in a 9-year follow-up study of smooth surface implants placed to support full jaw restorations in grafted bone (21). In this study the implant bridge was removed to enable an accurate registration of pocket depth and bleeding because the prosthetic design could otherwise hamper proper registration. Over 60% of the implants showed bleeding on probing, but despite this only 11% showed deep pockets (≥ 5 mm) and bleeding was not associated with bone loss. Only 7% of the implants showed bleeding

combined with bone loss exceeding 3 mm. Similarly, Dierens et al. (24) could not demonstrate correlations between probing depth and marginal bone levels around single implants functional for 16–22 years. Deep (> 5 mm) and shallow (< 4 mm) pockets were found in all bone level groups explaining the poor predictive value of probing for peri-implantitis. Additionally, 81% of the implants showed bleeding on probing, yet only 5.1% were classified as having peri-implantitis because of progressive bone loss over 2 mm in combination with a probing depth above 5 mm. The authors therefore questioned whether bleeding is a reliable parameter to detect detrimental disease in terms of bone loss around implants. The aforementioned papers point to the fact that radiographically detectable bone loss is probably the only reliable parameter to assess the prevalence of peri-implantitis.

Conclusions

There is strong evidence in the literature that the new generation of dental implants, with predominantly moderately rough surface topography, yield a better outcome in terms of implant survival than the first generation. Especially when considering that the currently applied surgical and prosthetic treatment protocols are more challenging. Moreover, patients with compromised conditions, whom in the past four decades have shown to be more prone to high implant failures and other complications, can today be treated in a more predictable way. However, despite the fact that the influence of implant topography on implant survival is well known, systematic evaluation of the literature focusing on its effect on peri-implant bone loss is lacking.

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