

Original article

X-ray evaluation at 5–6 years of Straumann implants (part 2)

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Discussion

Long term preservation of crestal bone height around osseointegrated implants is often used as a measure of primary success [5, 12, 22]. Prospective long-term studies exhibited survival and success rates largely exceeding 95% after 5 and 10 years of follow-up for the Straumann® implant system [3, 5, 18, 22, 45, 57]. A mean crestal bone loss ≤ 1.5 mm during the first year and ≤ 0.2 mm per year thereafter is proposed as one of the major success criteria. If we apply these strict success criteria then the CBL in 5 years should not exceed 2.3 mm [$1.5 + (0.2 \times 4)$].

In the current study, 8.5% of the implants exhibited “supra-boundary bone”. In addition to 84.5% of the implants showing bone loss within the physiological range (0–3 mm), giving an overall successful pool of implants up to 93%. This represents a high success rate considering the private practice setting and the absence of exclusion criteria in the initial enrolment of the patients.

Patients with implants exhibiting a bone loss of 2–3 mm (7.8%) would require careful monitoring, with closer hygiene recalls and increased education in regard to patient awareness for dental hygiene and maintenance.

Bone loss greater than 3 mm was observed in 7% of the included implants. At the 5–6 year control, they were still well integrated in the jaw bone and the subjects did not manifest any symptoms that previously identified them as unsuccessful [7]. Moreover, the status and prognosis of such implants have to be carefully interpreted because other factors, mainly clinical parameters such as bleeding on probing and pocket depths, were not available, in contrary to previous studies [5, 12, 31, 38, 39, 45–47, 51]. Considering such arguments, and although these implants were put by the study group in the unsuccessful implants category, one could argue the contrary. This group deserves careful monitoring, with closer hygiene recalls, more follow-up radiographs, and extended patient awareness to dental hygiene.

For the Straumann® implants, the distance from the implant shoulder to the first bone–implant contact was called

DIB (distance implant–bone) and was used in previous studies [16, 21]. These studies followed the changes in peri-implant bone levels over time by taking measurement between two time points. A baseline and a postoperative radiograph were usually taken to identify initial and final bone levels, and therefore to calculate the difference: Δ DIB.

In the present study, an original method was used to calculate the bone change: the interface of the smooth-roughened surface (identified as the R interface) was considered as the baseline level. It was assumed to be the level up to which bone loss was considered as physiological, i.e. not affected by external factors. Bone loss occurring further from this point, in an apical implant direction, was thus identified as crestal bone loss (CBL). Bone localized coronally to this interface was defined as “supra-boundary bone”. When the bone level was stabilized at the interface, it was then considered that no bone change occurred (CBL and “supra-boundary bone” were equal to 0 mm).

From that point, it was interesting to identify factors that might enhance bone loss or favor bone maintenance when single-staged Straumann® implants with treated TPS/SLA surfaces were used. It could be argued that the mean CBL was even lower than the 1.2 mm obtained in this study, as this value was compensated with implants that had what was called “supra-boundary bone”. The present study did not quantify this “supra-boundary bone”, as was described in a recently published study [51].

A paralleling radiographical technique may sometimes be difficult to perform because of the implant inclination and patient anatomy. For example, in the case of an extremely resorbed mandible, the intra-oral placement of the film was impossible because of the interference of the mouth floor [33]. In the maxilla, where the palate is the most inclined, it was difficult to position the film without bending [34]. This explained the large number of un-interpretable radiographs in these two regions.

When observing the comparative tables for the statistically significant results, namely surface texture, smoking status, anterior/posterior location and VBL, it is worth noticing

that they strongly influenced both extremes of bone change groups, i.e. bone loss higher than 3 mm and bone occurring above the rough-smooth surface ("supra-boundary bone"). For example, a TPS-surfaced implant, an implant placed in a smoker, an implant localized in an anterior arch, and an implant with VBL < 1 mm showed higher differences than their counterparts in zones of bone loss > 3 mm (higher bone loss) or in zones of "supra-boundary bone" (least "supra-boundary bone"). Their influence became low in zones of physiological bone loss (0–3 mm).

Statistically significant factors affecting bone loss

Surface texture effect

In the past 15 years, the topography of titanium surfaces has been investigated for dental implant applications [7, 16, 21, 37, 56]. The main goal of these experimental studies was to determine whether bone apposition could be enhanced by new microrough titanium surfaces as compared with the original implant surfaces utilized in implant dentistry, such as machined or titanium-plasma-sprayed (TPS) surfaces. Various techniques have been used to produce microrough titanium surfaces, including sandblasting, acid etching, or combinations of those, to modify surface topography. SLA surfaces were shown to have greater success and survival rates than TPS surfaces in several animal (miniature pigs) studies and human studies [70–73].

Among these new surfaces, the sandblasted and acid-etched (SLA) surface demonstrated enhanced bone apposition in histomorphometric studies and higher removal torque values in biomechanical testing [71–74]. Based on these experimental results, clinical studies were initiated to load SLA implants after a reduced healing period of only 6 weeks. In the study of Cochran *et al.* [71] comparing TPS with SLA surfaces in the canine mandible, linear measurements on standardized radiographs from the implant shoulder to first bone-to-implant contact (DIB) were done and bone density was evaluated by computer-assisted densitometric image analysis (CADIA). DIB measurements indicated that SLA implants significantly showed less bone height loss (0.52 mm) than TPS implants (0.69 mm). Histometric findings by the same groups later confirmed these results. The SLA implants exhibited significantly higher percentage of bone-to-implant contact than did the TPS implants [72]. The clinical examination up to 3 years demonstrated favorable results, with success rates around 99% [71]. A more recent study revealed very high success rates for SLA surfaced implants loaded at 6 weeks and placed in the posterior maxilla [74].

To date, this study is the first to have equally large numbers of each surface. The present study also clearly yielded significant higher bone loss on the TPS implants than on the SLA surface implants. Moreover, the TPS group had a greater proportion of implants having bone loss > 3 mm. The TPS surface became more significant in terms of degrees of bone

loss when combined with other factors such as smoking, anterior location and VBL prior to implant placement smaller than 1 mm. The proportion of bone above the rough-machined interface (named "supra-boundary bone" in the current study) was also significantly higher on the SLA surface. Therefore, it may be prudent to establish a more intense oral hygiene follow-up for patients with TPS-surfaced implants, especially if other aggravating factors, such as tobacco use, are present.

Of note, however, is that TPS surfaced implants still osseointegrated well and have contributed to the high survival rate of the study. Hence, although they have greater crestal bone loss (lower success rates), TPS surfaced implants still represent a valid treatment option for implants in function.

Tobacco effect

The effect of tobacco on dental implants is well documented in the literature and many authors have shown that heavy smokers show a greater degree of crestal bone loss when compared to non-smokers [49, 59, 65, 75]. However, the underlying mechanisms are not yet completely understood. Smoking is thought to interfere with early healing events in the process of osseointegration and hence the consequences are usually recognized in the first year following implant placement. Lindquist *et al.* [59] reported that smokers demonstrated worse oral hygiene and displayed approximately 3 times greater bone loss after 10 years than non-smokers. Moreover, factors including heavy or unfavorable occlusal loading previously associated with increased peri-implant loss became more relevant with smoking [49].

Smoking and poor oral hygiene were found to be of greater influence on peri-implant bone loss than overload in long-term studies of patients treated with fixed partial dentures [24, 59]. Other studies showed that smoking and implant location in the maxilla were associated with an increased peri-implant marginal bone resorption [75].

It was however argued that smoking should not be an absolute contra-indication for implant therapy. Long-term heavy smokers would rather be informed of the increased risk of marginal bone loss at the implant site over the long-term, and eventually a higher risk of late implant failure [75]. In the 10-year follow-up study of Carlsson *et al.* [77], smoking was the most important factor affecting peri-implant bone loss in the mandible. A number of reviews of the literature emphasize smoking as a significant risk factor for a compromised prognosis of dental implants.

In agreement with that, the current study showed that smokers manifest a statistically significant higher degree of crestal bone loss when compared with non-smokers. Additionally, this effect was significantly enhanced when considered with other factors (TPS surface, anterior location and VBL < 1 mm). Interestingly, smoking even provoked other non-statistically significant factors to increase bone loss; these include opposing fixed or mixed occlusion, mandibular location, and standard implant collar heights (Tables 22, 23 and 25). These combinations were however still not statistically significant.

Despite that tobacco significantly influenced the implant success rates; it did not significantly lower the survival rate. Based on this result, one could argue that it cannot be considered a contra-indication for implant placement.

Oral hygiene and periodontal status effect

Oral hygiene and periodontal status are also of importance in regard to peri-implant bone loss and implant failure [55]. Isidor [39] found a progressive loss of radiographic bone and clinical probing depths at implants with enhanced plaque accumulation.

Although optimum dental hygiene was emphasized in the current study, patients were not enrolled in active and regular recall session. One might therefore assume that preliminary caries and pocket control – a procedure done systematically in the current study – is of a greater importance than strict post-treatment recall sessions. Consistency or frequency of recall and its effect on bone loss were not investigated in this study.

Implant location effect

Contradicting data in the literature have been reported on the effect of implant location (anterior versus posterior), on their success and survival rates. Weber *et al.* reported higher bone loss in the anterior region, although the size of the data was small [16]. Also, a 15-year prospective study demonstrated that implants placed in anterior segments showed higher bone loss than in the posterior segments [22]. Similarly, mesially placed implants showed more bone resorption than distally positioned implants, independently of implant surface roughness [14]. Lindquist *et al.* suggested that the more extensive bone loss around the anterior implants was a consequence of tensile forces, caused by loading of the posterior cantilever extensions and other biomechanical factors [24].

It is also debatable that implants placed in the posterior region show higher bone loss, considering that occlusal forces also increase because of the closeness of the temporomandibular joint. Therefore, all the posterior implants supporting partial prosthesis would experience more loading than those located in the anterior regions. Precisely, in a prospective 5-year study [20], the cumulative success rates for implants placed in molar sites were lower than mandibular and maxillary anterior regions. These differences reported for the anterior and posterior locations were attributed to bone quality and quantity (difficulty in achieving bicortical stabilization). Posterior regions were often characterized by unfavorable bone quality and reduced bone height, thus affecting bone loss and implant survival rate [78, 79]. Implants placed in the premolar or molar regions were generally shorter than those placed in the canine and incisor sites [64]. All of the above mentioned studies actually correspond to machined surfaced implants. With the introduction of roughened surfaces, research showed that posterior regions are no longer a risk factor.

Present results reported significant higher bone loss for implants placed in anterior regions. The combination of anterior region placement, tobacco use, and TPS-surfaced implant greatly increased bone loss. However, the results should be carefully interpreted as many of the anterior implants were usually placed deeper than those in the posterior region, to prevent exposure of the metal implant margin. Consequently, in addition to the crestal bone resorption which occurred for implants placed under standard conditions, bone adjacent to the polished implant surface was also lost. From a biological point of view, the subcrestal placement of the rough-smooth interface was consequently not recommended [27, 61].

Most of the posterior implants in the present study were short length. Due to the encouraging results in terms of CBL around posterior implants as opposed to anterior ones, short implant lengths could also be considered a valid treatment option and one with similar success rates to longer implants, especially in areas of reduced bone height.

Vestibular bone lamella width effect

The effect of VBL at implant placement on bone loss has not yet been reported in the literature. It is documented that a minimum width of 1 mm around implants, is required at placement to obtain optimum osseointegration and to prevent exposure of the implant threads following bone remodeling [5]. Primary stability was reported to be an even more significant factor for osseointegration [5, 56].

Bone that is less than 1 mm wide was thought to be more susceptible to resorption after surgery or following function. The rationale was that this minimal bone would fail to provide a sufficient matrix for the surrounding mesio-distal bone remodeling process, and would even enhance its resorption [12, 47, 77, 81]. Such findings should alarm clinicians while placing implants in anterior regions with a VBL less than 1 mm, since it may cause higher peri-implant bone loss and would therefore affect esthetic parameters, namely mesial and distal papillae.

There are reasons to suggest that over time this uneven outline of the marginal bone around dental implants was leveled out by a bone remodeling process and a reduction of the bone height at the proximal surfaces. Such an explanation is in agreement with findings reported by Carmagnola *et al.* [80] who, in a dog model, studied bone tissue reactions around implants placed in a compromised mandible. Following tooth extraction, the buccal bone plate was resected and a narrow ridge established. After 8 months of healing, implants were placed in the compromised site so that their lingual surfaces were invested in bone while about 4–5 mm of their buccal portion remained exposed. During the process of healing and during 4 months of function marked modeling and remodeling of the bone tissue around the implants took place. At the buccal surfaces some regrowth of bone occurred while at the lingual surfaces there was a substantial resorption of bone. As a result, the marginal level of osseointegration tended to become similar at all four aspects of the implants. This

finding could explain the greater proximal peri-implant bone loss around implants that have a buccal bone lamella that is smaller than 1 mm [51].

The width of the VBL showed a higher influence on CBL when combined with tobacco use, anterior arch location or TPS surfaced implants. The high value of CBL around implants having a VBL < 1 mm might be due to their anterior location which often involved a deeper fixture placement, this parameter was discussed previously. Moreover, implants with a VBL that is greater than 1 mm had more bone coronal to the R interface ("supra-boundary bone"), than those with a VBL that is less than 1mm.

Statistically non- significant factors affecting bone loss

All other investigated factors (implant diameter, opposing arch occlusion, maxillary versus mandibular jaw location, smooth collar height, fixed versus removable suprastructure, implant-implant or implant-tooth distance, and implant length) did not show a significant influence on bone remodeling in the current study. This could be attributed to the small number of patients who were concerned by these factors, errors in the radiographic analysis, or the actual negligible influence on bone remodeling and bone loss in the included patient sample. Nevertheless, when combined with other factors, some of these factors might influence bone levels. This will be discussed in the following paragraphs.

Implant diameter effect

Implant diameter is the distance between the peak of the widest thread and the same point on the opposite side of the implant. In contrast, implant diameter is distinct from the implant platform diameter, the latter being a measure of the interface of the implant connected with the abutment. Because a variety of implant widths and platforms are available, a wide-platform is not always related to an increased diameter of the implant thread. Implant diameter was not reported as a limiting factor in peri-implant bone loss [26, 82].

Reported advantages of using wide-diameter implants include: increased bone to implant contact, use as "rescue" implants in the case of site over-preparation during drilling, immediate placement in failure sites, reduction in abutment stresses and strain. The most obvious indication for wide-diameter implants (especially at the platform level) is for molar fixed rehabilitations [26].

Contrasting effects of implant diameter on success and survival rates were reported in the literature. Some studies report that 5 mm wide implants have higher failure rate than 3.75 or 4 mm wide implants because wider implants are often used in rescue procedures for failed implants [82]. Also, it has been reported that 5 mm wide implants developed for compromised situations had similar survival and success rates to standard-size Brånemark® implants.

Inversely, another study [83] showed that cumulative survival and success rates of small-diameter implants and standard-diameter implants were not statistically different ($p > 0.05$); although bone quality was a significant factor in failure, marginal bone loss was not influenced by the different implant diameters. The results suggested that small-diameter implants could be successfully used in the treatment of partially edentulous patients. Furthermore, no statistically significant relationship was observed between peri-implant bone loss and implant diameter [49, 84]. When considering wide neck ITI implants, a five-year life-table and radiographic analysis showed that these implants were highly predictable, with small prosthetic complications. The average bone loss measured at the two-year post-operative control was similar to standard implants [85].

No correlation between the different implant collar diameters on bone loss were noted in the present study. Wide neck implants did not show higher bone loss than smaller diameter implants. Moreover, combinations with other factors did not seem to have an effect.

Effect of opposing dentition

Occlusal overloading has been reported to be associated with increased bone loss and implant failure. This report was based on anecdotal observations supported by theoretical biomechanical theories, but was never proven in controlled studies in humans. Studies in monkeys demonstrated that overload could cause increase bone loss in some included implants [63]. Isidor [39] showed that overloaded implants had a decreased bone-to-implant contact. These overloaded implants also presented a smaller area in contact with mineralized bone tissue than non-loaded implants. Furthermore, once peri-implantitis has progressed, the control of occlusion and inflammation was probably not sufficient to promote the healing mechanism [18, 46, 65]. Implants with surrounding tissue inflammation probably deserve a greater care in avoiding overload. Again, these conclusions were drawn from studies done on machined surfaces.

Also, when reviewing the literature on the effect of the opposing dentition on bone loss, there was no conclusive answer to the question: did the prosthetic status in the opposing jaw influence the peri-implant bone loss and/or implant failure? Peri-implant bone loss may be enhanced in the jaw occluding with a fixed prosthesis in comparison with one occluding with a complete denture [86]. On the contrary, Carlsson *et al.* [77] did not experience such differences in peri-implant bone loss and suggested that the prosthesis in the opposing arch did not influence peri-implant bone loss.

The opposing dentition alone did not seem to influence bone loss in the present study. The combination of smoking and implants with a fixed or mixed opposing occlusion increased bone loss, unlike removable opposing dentition. This parameter deserves further analysis, since our results were not statistically significant.

Jaw location effect

Implant survival was lower in the maxilla than the mandible; this was attributed partially to a different bone quality in the maxilla [2, 14, 59, 65]. In the study of Carlsson *et al.* [77], all the failing – maxillary – implants (placed with 2-stage implant procedures) were lost during the healing period and not after the connection of the prosthesis. However, the same study reported similar peri-implant bone loss in both jaws.

Other studies revealed different results. A comparison between bone loss in the mandible and in the maxilla around 2-stage implants at abutment connection showed that a steady state was achieved after the first year of loading. The bone loss was 0.05 mm in the maxilla and 0.2 mm in the mandible for completely edentulous individuals wearing dentures [86]. Very few studies have been carried out on rough-surfaced implants [75], and in these no differences between maxilla and mandible were noted. A more recent study [87] showed that the implants located in the maxilla were associated with significantly higher bone loss.

No statistically significant differences in bone loss were noted around implants in the maxilla or in the mandible in the current study. However, the combination of smoking and mandibular location caused higher bone loss, unlike the combination of a maxillary location and a smoking subject. Further research on the influence of jaw location and bone conditions on oral implant outcomes are needed.

Effect of height of the smooth collar

It was shown that the height of the smooth implant collar has an effect on bone remodeling around the implant. Straumann® implants showed more marginal bone loss if the smooth part of the implant came into contact with the bone after a deeper placement [27]. This result led to the development of the “Esthetic” Plus line within the ITI Dental Implant System. The magnitude of initial bone remodeling around implants was dependant on the location of the rough-smooth border of the implant in an apico-coronal dimension [88]. The implant having the shortest smooth coronal collar showed no additional bone loss, while enabling deeper placement. Its use might reduce the risk of an exposed metal implant margin in areas of esthetic concern [81, 89].

The current study showed no significant difference between esthetic implants when compared with standard implants, in terms of crestal bone loss. This would be of interest as a deeper placement, especially in the anterior area, would jeopardize proximal bone.

Suprastructure effect

The systemic review of Berglundh *et al.* [12] has demonstrated that implants supporting overdentures exhibited higher frequencies of biological and technical complications

than implants with fixed reconstructions. A seven-year study reported similar survival rate for implants supporting single-tooth prostheses (95.6%), cantilever fixed partial prostheses (94.4%), fixed partial prostheses (96.1%), fixed complete prostheses (100%), and implant/tooth-supported prostheses (90.6%) and overdentures (95.7%) [89]. Mericske-Stern [62] observed that patterns of force transmission onto the implants were similar with a fixed complete denture and an overdenture connected to maxillary implants. The influence of mechanical and anatomical-prosthetic variables on peri-implant parameters was studied by several authors [48, 61–63, 89]. The type of the implant to denture attachments was shown to have little or no influence on the peri-implant parameters [90, 91]. The bar design did not significantly influence the occlusal force distribution pattern. Wyatt and Zarb [17] observed that implants supporting distal extensions prosthesis significantly increased bone loss in the first year of loading when compared to implants supporting prosthesis bounded by natural teeth.

Excessive marginal bone loss was explained by the overloading due to the lack of anterior contact and the presence of parafunctional activity [77]. It was shown that 70% of the occlusal forces were borne by the distal cantilevers and 30% by the implant-supported segment of the prosthesis on “Toronto bridges” or “Branemark bridges” [60, 61]. Biomechanical calculations and such results suggested that the most distal implants presented higher risk of bone loss because they were exposed to the largest forces, bending movements and stress concentrations. Subsequently, Nedir *et al.* did not experience lower survival rates of rough surfaced implants having a single unit distal extension [66].

In the present study, a removable suprastructure did not manifest greater peri-implant bone loss, despite the advanced age and presumed reduced dexterity of older patients. Overdentures do not represent a higher risk for the development of peri-implant lesions. Elderly patients with overdentures supported by attachments or bars can reasonably maintain healthy peri-implant conditions. The small sample of patients with a removable prosthesis might also explain the non-significance of the results.

Implant-tooth/implant-implant distance effect

Few investigations which assess the influence of the distance between implants or between implants and teeth in regard to bone loss are reported in the literature. Effects on the interdental papilla were thoroughly studied by Tarnow *et al.* [92]. This group observed that increased crestal bone loss would result in an increase in the distance between the base of the contact point of the adjacent crowns and the crest of bone. It is a proposed way to determine whether the papilla will be present or absent between two implants, and was previously reported between natural teeth. When multiple implants had to be placed in the esthetic zone, the use of small diameter implants might preserve at least 3 mm of bone at the implant-abutment level between them. Differences between

implant diameters did not however yield significant results when considering their effect on peri-implant bone remodeling, however, further research is needed.

No correlations between implant-implant or implant-tooth distances and mean bone level change were established in the present study.

Implant length effect

Reported studies on smooth-surfaced implants showed that short implants failed more frequently than longer ones [21, 60, 64, 95]. Historically, the use of short implant was not widely recommended because it was believed that occlusal forces might be dissipated over a large implant surface area to prevent excessive stresses at the interface [81]. However, finite element analysis (FEA) has shown that the occlusal forces are mainly distributed to the crestal bone, rather than evenly throughout the entire surface area of the implant interface [63]. Since masticatory forces were usually light and fleeting, they are normally well tolerated by the bone. This might explain why the implant length was not linearly related to biomechanical stability. Long term studies show a dramatic increase in failures for implants shorter than 7 mm in length, especially on machined surface implants, even more in type 4 bone [93].

Smoking, implant location and morphology, which were demonstrated to influence marginal bone loss, also associated with an increased failure rate with short implants [94]. Similarly, it was demonstrated that short implants, wide implants, implants supporting fixed prostheses, and implants placed in smokers were associated with a high CBL [49]. Implant length was the most significant factor in the maintenance of machined surfaced dental implants.

However, the introduction of rough surfaced implants has allowed a greater bone-to-implant contact; hence, higher success and survival rates were noted. Bernard *et al.* [94] suggested that the distinct magnitude of anchorage and the distinct loosening patterns registered for Brånemark® and Straumann® implant systems of different lengths might be related to the various surfaces. Greater torque forces were needed for rough implants of short length, unlike for implants with machined surfaces. Implants as short as 5 mm in length, with porous surface treatments, were introduced to replace possible sinus lift procedures [94]. Based on such observations of increased bone-to-implant contact on rough surfaces, private practitioners used short implants in various situations (e.g. in posterior maxilla with limited bone height or in posterior mandibular locations because of the proximity of the mandibular canal), they showed that short implants were as successful as long ones [64].

Renouard *et al.* [96] also demonstrated that the use of short implants could be considered for prosthetic rehabilitation of the severely resorbed maxilla as an alternative to more complicated surgical techniques; both implant failure rate and bone resorption over two years were not affected.

Mean marginal bone loss and gingival crevice probing depth associated with short or long implant lengths were

statistically comparable [50]. Accordingly, when considering the long-term multicenter evaluation of 2359 non-submerged Straumann® implants [21], the five year survival and success rates of 8 mm long implants did not differ significantly from the longer implants, despite the posterior placement of the shorter implants.

Peri-implant bone loss was quite similar for long and short implants in the present study, even when combined with other factors. Moreover, implants placed in the posterior area –that tended to be shorter for anatomical reasons- exhibited less bone loss than those placed in anterior areas. That confirmed the previous observation that length of rough-surfaced implant did not influence bone loss and implant success. This was a significant finding which might not only simplify surgical and planning procedures, but also might drastically expand the applications of implant therapy.

Other factors worthy of investigation

Further analysis on the effect of other factors on peri-implant bone remodeling might include prosthesis-related factors: the type of fixed suprastructure (single crown or fixed partial denture), nature of the fixed partial denture (two splinted crowns, a bridge, and a cantilever), misfit of the suprastructure, and crown to implant ratio [97].

The effect of the level of implant submersion and the delay of placement or loading might be also of interest. Patient periodontal status and number of visits to the hygienist are also shown to affect bone remodeling around implants. Other studies have observed that crestal bone level changes were correlated with the presence of a microgap even when a two-part implant (i.e. implant plus an abutment) was placed with a non-submerged technique [10]. When the microgap was located above the bone crest, less bone remodeling occurred; whereas when the microgap was placed below the bone crest, greater amounts of bone were lost. The lack of data in the studied population prevented the inclusion of the factors described above.

Conclusions

The conclusions of this study can be summarized in eight points. Some of these were already known and were thus confirmed; others were identified, in particular some interesting associations identifying some groups at risk:

- 1) The survival rate (99.2%) presented hereby compared well with related previously published studies.
- 2) Specific peri-implant bone loss beyond the smooth-rough implant interface was on average 1.2 mm, throughout a period of 5-6 years. Such value was in agreement with those reported in the literature on rough surface implants to date.

The radiographic method used for the evaluation could be described as unique: the bone level change was evaluated

from the smooth-rough implant interface considered as the baseline level; therefore, the measurements were done from 5-6 year post-operative radiographs only. The results confirm the reliability of the measurements.

- 3) The success rate (93%) was mainly based on the percentage of implants having CBL greater than 3 mm. These were considered as a higher failure risk group. Different criteria for success rate evaluations were used in different studies.
- 4) Two subpopulations within this study, presented higher failure risk groups, and should be monitored more closely and attentively when considering hygiene control and while establishing the treatment planning process:
 - 4.1 The first group represented 7% of the total population. It showed a CBL higher than 3 mm, which was considered as "alarming" by the study group.
 - 4.2 The second group included a population with the following factors: TPS-surfaced implants, anterior arch location, smokers, and VBL thinner than 1 mm at surgery. These factors – considered separately or combined – were associated with higher peri-implant CBL.
- 5) "Supra-boundary bone"; which is bone appearing above the rough-smooth interface was observed on 7.8% of the included implants. It was quite noticeable with SLA-surfaced implants, non-smoking subjects, implants located in a posterior arch, and implants with a VBL higher than 1 mm at surgery. These can be considered as "low failure risk groups".
- 6) Implants placed in the mandible, implants with an opposing mixed/fixed occlusion and implants supporting a removable suprastructure tended to cause higher bone loss, although results were not statistically significant.
- 7) Short implants showed a very limited bone loss, the difference in bone loss between short and long implants was not statistically significant. This confirmed the reliability of the use of short implants.
- 8) Systemic and continuous monitoring of peri-implant bone conditions along with the identification and control of associated risk factors are highly recommended for the diagnosis of peri-implant disease.

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