

Marginal bone loss at implants with different surface characteristics - A 20-year follow-up of a randomized controlled clinical trial

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Abstract

Objective: This report is a 20-year follow-up of a randomized controlled clinical trial evaluating the potential long-term effect of a modified implant surface on the preservation of the peri-implant marginal bone level.

Material & Methods: In each of 51 patients and for each fixed partial denture (FPD), by randomization at least one implant installed had a non-modified *turned* surface and one a modified and *roughened* surface (TiOblast®). Clinical and radiological examinations were performed at various follow-up intervals. Primary outcome variables were peri-implant marginal bone level change from time of loading and proportion of implants with no bone loss at 20 years. Multilevel analysis followed by nonparametric and Pearson's Chi-Square tests were applied for statistical analysis.

Results: At the 20-year follow-up, 25 patients carrying 64 implants were available for evaluation. Turned and TiOblast implants presented with a mean bone level change from the time of FDP delivery amounting to -0.41 mm (95% CI $-0.84/0.02$) and -0.83 mm (95% CI $-1.38/-0.28$) respectively (inter-group comparison $p > .05$). 47% of the Turned and 34% TiOblast implants ($p > .05$) showed no bone loss. All but one of these implants were free of bacterial plaque and inflammation as well as presented with probing pocket depths ≤ 5 mm at both the 5- and 20-year follow-up examinations.

Conclusion: It is suggested that a moderate increase of implant surface roughness has no beneficial effect on long-term preservation of the peri-implant marginal bone level.

KEYWORDS

bone loss, clinical, dental implants, long-term follow up, radiology

1 | INTRODUCTION

Most of the dental implants used today are designed with a modified surface. Evidence from animal studies verified enhanced bone-to-implant contact and removal torque values with increasing surface roughness (Shalabi, Gortemaker, Van't Hof, Jansen, & Creugers, 2006). These findings encouraged the use of

revised protocols for implant therapy, including immediate post-extraction placement (Lang, Pun, Lau, Li, & Wong, 2012) and immediate loading (Esposito, Grusovin, Maghaireh, & Worthington, 2013; Sanz-Sanchez, Sanz-Martin, Figuero, & Sanz, 2015). But a central question remains: to what extent does implant surface characteristics influence the long-term maintenance of the peri-implant bone support?

In a systematic review on the occurrence of peri-implantitis in relation to implants with different surface characteristics, it was reported that subjects treated with implants with a non-modified surface had, compared to subjects with modified surface implants, a 20% reduced risk to be affected by this inflammatory condition (Esposito, Ardebili, & Worthington, 2014). The evidence was limited to data from only four RCTs with few participants and relatively short follow-up periods (≤ 3 years). A further concern with regard to peri-implantitis is that this disease (lesion) is not caused by a modified surface *per se*, but by bacterial biofilms on the implant. Accordingly, if surface characteristics have an influence on the initiation and progression of the peri-implantitis, bone loss must first take place to allow exposure of the implant surface to bacterial biofilm formation. A pertinent question in relation to the use of implants with non-modified and modified surfaces is therefore whether they differ with regard to long-term preservation of the peri-implant bone support. A recent systematic review (Doornierwaard et al., 2017), including both retrospective and prospective studies with ≥ 5 years of follow-up, concluded that peri-implant bone loss was significantly smaller around non-modified (minimally rough) implants than at implants with modified surface characteristics. Thus, the proportion of implants with a marginal bone loss of >2 mm was 14% for non-modified implants as compared to 18%–20% for implants with modified surfaces. However, the heterogeneity of the studies included and the presence of confounding factors suggested a careful interpretation of the data with regard to their clinical relevance. Hence, to strengthen the evidence for a potential relationship between surface characteristics and longitudinal peri-implant marginal bone loss additional long-term data from RCT studies are desirable.

In a previous publication (Wennström, Ekstubb, Gröndahl, Karlsson, & Lindhe, 2004) the 5-year results were reported of a prospective, randomized controlled trial in periodontitis susceptible subjects comparing implants with non-modified and modified surfaces. With the intra-individual and intra-prosthesis randomization design used the effect of confounding factors was minimized. The results showed that bone loss (i) during the first year of function as well as annually thereafter was small and (ii) did not vary between the two types of implants. The current paper reports on 20 years of follow-up of the patients enrolled in this prospective RCT study with focus on potential differences regarding long-term preservation of marginal bone levels between implants that differ only with respect to surface characteristics.

2 | MATERIAL AND METHODS

The original study sample of the RCT study comprised 51 partially dentate patients (mean age 59.5 years, range 36–80 years) who during the time period 1992–1995 were referred to the Clinic of Periodontics, Public Dental Services, Gothenburg, Sweden for treatment of moderate-to-advanced chronic periodontitis and subsequently were restored with implant supported fixed partial dentures (FPD). At least two implants were used to support a freestanding

FPD. The original study protocol was reviewed and approved by the Human Ethics committee at the University of Gothenburg (Dnr. 78–91), and written informed consent was obtained from all participating subjects at the time of enrolment.

The RCT study was designed for randomized installation of two types of Astra Tech implants (Astra Tech® Dental Implant System, Mölndal, Sweden) that differed with regard to surface characteristics only. Thus, in each subject and for each FPD, by randomization every other implant installed had a non-modified (turned) surface and every other a modified, roughened surface (TiOblast®). Details regarding case selection, randomization, surgical, and prosthetic procedures were reported by Wennström et al. (2004). Briefly, two experienced periodontists at the Clinic of Periodontics performed all surgical procedures. At completion of the preparation of the recipient sites, the sealed envelope containing the computer-generated randomization code with regard to the implant type to be installed in the most anterior implant-site was made available and implants were installed accordingly as every other implant. In total 149 screw-shaped and self-tapping implants were placed – 83 in the maxilla and 66 in the mandible. All implants had a diameter of 3.5 and a length ranging from 8 to 19 mm.

Standard Uni-abutments® (Astra Tech® Dental Implant System) were connected at a second stage surgery 3 (mandible) or 6 (maxilla) months from the time of implant installation. The prosthetic treatment was carried out according to the manual provided by the manufacturer and the final screw-retained FPDs were delivered about 4 weeks after abutment connection. The baseline clinical and radiographic examination for the prospective follow-up investigation was performed immediately following FPD placement. Annual recalls for supportive care and clinical and radiographic examinations were carried out for the first 5 years post-treatment, and outcomes following this time interval have previously been reported (Wennström et al., 2004). After the 5-year re-examination the referring dentists acknowledged responsibility for the continued supportive care.

2.1 | Clinical and radiological follow-up examinations

Participants, care providers as well as examiners were unaware of the randomization sequence for implant placement throughout the study period.

The subjects were invited to the Clinic of Periodontics at 8, 12, and 20 years for follow-up examinations. Clinical parameters recorded were: pain from the implant region and presence of plaque, sign of inflammation (bleeding on probing, BoP) and probing pocket depth (PPD) to the nearest millimeter at four sites of each implant (for details see Wennström et al., 2004).

Standardized intra-oral radiographs were obtained using a parallel technique. One experienced radiologist (AE), who was masked with respect to implant surface characteristics, examined all radiographs taken from baseline to the 20-year follow-up. In the radiographs, the distance between the implant shoulder and the “marginal bone to implant contact” level was determined at

the mesial and distal aspect of each implant. In analogue radiographs measurements were performed with the use of a magnifying lens ($\times 7$). Digital radiographs were displayed in Sectra IDS7 PACS (Sectra Imtec AB, Linköping, Sweden) on a 20-inch monochromatic screen (OLORIN Medic Line ML 187D TFT-LCD; Olorin AB, Kungsbacka Sweden). The screen resolution was 1280×1024 pixels. The measuring tool of the software was employed for the measurements. All measurements were made to the nearest 0.1 mm. The error inherent in the radiographic assessments was determined and the mean difference between repeated readings was 0.04 mm (SD 0.33).

2.2 | Data handling and analysis

For clinical assessments (PPD, BoP, plaque) the highest value recorded at the mesial, buccal, distal or lingual sites of the implant was selected to represent the implant site. The mesial and distal radiographic bone level assessments were averaged for each implant. Mean values, standard deviations, 95% confidence intervals and frequencies were calculated for data description. Primary outcome variables were marginal bone level change from time of loading and proportion of implants with no bone loss at 20 years. Peri-implantitis, defined as bleeding on probing/suppuration and a documented bone loss of >1 mm, was analyzed as a secondary outcome variable. Clinical data were considered as descriptors.

Data analysis was performed based on both a *modified intention-to-treat* (MITT; all patients available at the various time intervals and no data imputation for missing patients) and *per-protocol* (patients available at the 20-year follow-up) principles. A multi-level analysis based on patient and implant levels was performed. As the variance at patient level was not statistically significantly different from 0, implant level analysis for independent samples was selected. Normality of data could not be confirmed by Kolmogorov-Smirnov test, therefore a Mann-Whitney *U* Test was applied to evaluate potential difference in bone level change between patients maintained until the 20-year follow-up examination and subjects lost during the time of follow-up as well as for comparison of mean bone level changes related to type of implants (i.e. non-modified vs. modified). The Pearson's Chi-Square test was applied to assess differences in proportion of implants without bone loss at 20 years, as well as proportions of implants

presenting with peri-implantitis and various clinical variables (i.e. plaque, BoP and PPD category). A *p*-value of $< .05$ was considered to represent a significant difference in all analyses. All analyses were performed with a statistical software package (SPSS 24, SPSS Inc., Chicago, Illinois, USA).

3 | RESULTS

3.1 | Patients and implants lost to the 20-year follow-up

Of the 51 patients and 148 restored implants enrolled in the RCT study, four subjects and 11 implants were lost to the follow-up at 5 years (see Wennström et al., 2004). Additional 22 patients and 73 implants were lost between the 5- and 20-year interval. Hence, after 20 years 25 patients carrying 64 implants were available for evaluation (Table 1). Of the 26 patients who were lost during the follow-up period of 20 years, 19 patients had died (15 maintained all their implants at the last follow-up visit and four had experienced fracture of one or more implants), while seven discontinued the follow-up examinations at various time points because of severe illness or geographical relocation.

Of the 148 restored implants, 84 were lost to the final follow-up; one implant (modified surface) was explanted after 9 years due to disintegration, 17 had fractured (11 non-modified and 6 modified), 52 belonged to deceased patients and 14 to subjects who dropped-out for other reasons. If only clinically verified failures are considered, the overall failure rate after 20 years of function, was 12.2% (18 out of 148) on the implant level and 19.6% (10 out of 51) on the subject level. Of the 17 implant fractures recorded, 14 were positioned in the premolar/molar region, 9 affected implants supporting FPDs with cantilevers (5 patients) and 6 occurred in 3 subjects with history of bruxism.

Table 2 describes characteristics of the patients who returned for the 20-year follow-up examination ($n = 25$) compared to those who were lost to follow-up ($n = 26$) as well as the original patient sample ($n = 51$). No significant differences were observed regarding subject-related variables (age, gender, smoking habits, and jaw restored) or implant-related variables (distribution of implant types, number of crown units per implant, or clinical variables and bone level change at the 5-year follow-up).

TABLE 1 Number of patients and implants at the various examination intervals

	No. of patients	Reasons for loss of patients to follow-up		No. of implants	Reasons for loss of implants to follow-up		
		Deceased	Drop-out		Explanted/Fracture	Deceased patient	Drop-out
FPD placement	51			148			
5 years	47	3	1	137	3	6	2
8 years	44	2	1	124	5	5	3
12 years	34	8	2	90	8	22	4
20 years	25	6	3	64	2	19	5

TABLE 2 Baseline characteristics of patients and implants as well as mean peri-implant bone level change at 5 years of follow-up for the 20-year sample ($n = 25$) compared to the original patient sample ($n = 51$) and subjects "Lost to follow-up" ($n = 26$)

Subject characteristics Baseline	Original sample ($n = 51$)	Lost to follow-up ($n = 26$)	20-year sample ($n = 25$)
Age (mean; S.D.)	59.5 (9.7)	58.2 (7.6)	57.6 (10.0)
Gender (female)	61%	62%	68%
Smokers	33%	38%	28%
Jaw of treatment (maxilla)	55%	57%	52%
Implant-related factors Baseline	Original sample ($n = 148$)	Lost to follow-up ($n = 84$)	20-year sample ($n = 64$)
Turned/TiO-blasted	73/75	41/43	32/32
Mean no. of crown units per implant	1.30	1.32	1.27
5-year follow-up ^a	($n = 137$)	($n = 73$)	($n = 64$)
Turned/TiO-blasted	67/70	35/38	32/32
Mean bone level change Baseline–5 years (S.D.)	−0.41 (1.01)	−0.48 (1.00)	−0.33 (1.01)
Plaque ^b	11.9%	14.7%	7.8%
Bleeding on probing ^b	11.1%	13.3%	9.3%
PPD ^c mean (S.D.)	3.7 (1.17)	3.8 (1.27)	3.6 (1.03)
≤3 mm	63.7%	62.7%	65.5%
4–5 mm	25.1%	25.4%	25.0%
≥6 mm	11.0%	11.9%	9.5%

^a11 implants (5 TiO-blasted and 6 Turned) were lost to follow-up at 5 years.

^bPlaque or Bleeding on probing recorded at ≥1 sites of the implant.

^cProbing pocket depth: Mean value (SD).

TABLE 3 Clinical conditions at 5 and 20 years of follow-up – implant level

	Non-modified (Turned)			Modified (TiO-blasted)		
	5 years			5 years		
	All ($n = 67$)	Per protocol ($n = 32$)	20 years ($n = 32$)	All ($n = 70$)	Per protocol ($n = 32$)	20 years ($n = 32$)
Plaque ^a	14.9%	6.2%	14.8%	7.4%	9.3%	25.9%
Bleeding on probing ^a	13.4%	9.3%	11.1%	10.3%	9.3%	25.9%
PPD ^b mean (S.D.)	3.5 mm (1.01)	3.4 mm (0.84)	3.7 mm (1.03)	3.8 mm (1.28)	3.8 mm (1.13)	4.0 mm (1.30)
≤3 mm	68.7%	71.8%	59.3%	58.8%	59.3%	48.2%
4–5 mm	22.3%	21.8%	29.6%	27.9%	28.1%	33.3%
≥6 mm	9.0%	6.4%	11.1%	13.3%	12.6%	18.5%

Differences in proportions of scoring units between groups: $p > .05$ (Pearson's Chi-square test).

^aPlaque or Bleeding on probing recorded at ≥1 sites of the implant.

^bProbing pocket depth: Difference in mean value between groups: $p > .05$ (Mann–Whitney Test).

3.2 | Clinical conditions at 20-year follow-up

The clinical conditions at the non-modified and the modified implants at the 5- and 20-year follow-up examinations are reported in Table 3. The modified intention-to-treat (MITT) analysis compares the actual numbers of implants available for examination at the 5- and 20-year follow-ups. Whereas the non-modified

implants showed rather small alterations in the clinical condition between the 5- and 20-year follow-up examinations, the modified surface implants presented somewhat less favorable conditions.

The per-protocol analysis included implants that were retained in the study until the final follow-up examination (Table 3) and revealed an increase between the 5- and 20-year examination intervals in the proportion of implants showing presence of plaque and bleeding on

TABLE 4 Mean bone level change in mm $\pm$ SD (95% Confidence interval) from baseline (FPD connection). Implant level

Modified Intention-to-treat analysis				Non-modified (Turned)				Modified (TiO-blasted)				Sign. ^a
Baseline to	n	Mean $\pm$ SD	95% CI	n	Mean $\pm$ SD	95% CI		n	Mean $\pm$ SD	95% CI		
5 years	67	-0.33 $\pm$ 1.07	(-0.58/-0.08)					70	-0.48 $\pm$ 0.95	(-0.70/-0.26)		ns
8 years	53	-0.32 $\pm$ 1.21	(-0.64/0.00)					59	-0.57 $\pm$ 1.18	(-0.87/-0.27)		ns
12 years	32	-0.37 $\pm$ 1.20	(-0.78/0.04)					30	-0.58 $\pm$ 1.28	(-1.03/-0.13)		ns
20 years	32	-0.41 $\pm$ 1.25	(-0.84/0.02)					32	-0.83 $\pm$ 1.59	(-1.38/-0.28)		ns
Per-protocol analysis				Non-modified (Turned)				Modified (TiO-blasted)				Sign. ^a
Baseline to	n	Mean $\pm$ SD	95% CI	n	Mean $\pm$ SD	95% CI		n	Mean $\pm$ SD	95% CI		
Baseline-5 years	32	-0.20 $\pm$ 1.10	(-0.58/0.18)					32	-0.48 $\pm$ 0.92	(-0.79/-0.17)		ns
5-20 years	32	-0.21 $\pm$ 1.20	(-0.62/0.20)					32	-0.35 $\pm$ 1.06	(-0.71/0.01)		ns
Baseline-20 years	32	-0.41 $\pm$ 1.25	(-0.84/0.02)					32	-0.83 $\pm$ 1.59	(-1.38/-0.28)		ns

n, number of implants with radiographic bone level data available at the various follow-up intervals.

^aMann-Whitney Test between non-modified and modified implants; ns = $p > .05$.

probing as well as pockets ≥ 6 mm for both categories of implants. The deterioration of the clinical conditions was more pronounced for the modified than for the non-modified implants, but the differences were not statistically significant.

3.3 | Peri-implant bone level change

The mean marginal bone level change that took place during the 20 years of follow-up, based on MITT and per-protocol analyses, is reported in Table 4. Although the mean bone level change was small at all follow-up examinations, implants with a modified surface showed somewhat larger mean change than the non-modified implants. At the 20-year examination non-modified and modified implants presented with a mean bone level change (from the time of FDP delivery) of -0.41 mm (95% CI -0.84/0.02) and -0.83 mm (95% CI -1.38/-0.28) respectively. The difference in bone level change between the two types of implants was not statistically significant.

The cumulative distribution of implants with modified ($n = 32$) and non-modified ($n = 32$) surfaces according to degree of *peri-implant bone loss* between baseline and the 20-year follow-up is reported in Figure 1. 47% and 34% of the non-modified and modified implants, respectively, showed no bone loss after 20 years of function ($p > .05$), while a bone loss of ≥ 2 mm was observed at 5 non-modified (16%) and 4 modified (13%) implants. A more detailed analysis of the 26 implants that showed no bone loss after 20 years in function revealed that all but one implant were free of plaque and signs of inflammation and presented with probing pocket depths < 6 mm at both the 5- and 20-year examinations.

At the 20-year examination peri-implantitis was identified at 7 of the 64 implants (10.9%; 2 non-modified and 5 modified implants in 5 patients). In addition, one patient (2 implants) had received surgical treatment for peri-implantitis after 8 years and showed after that no clinical pathology or further bone loss.

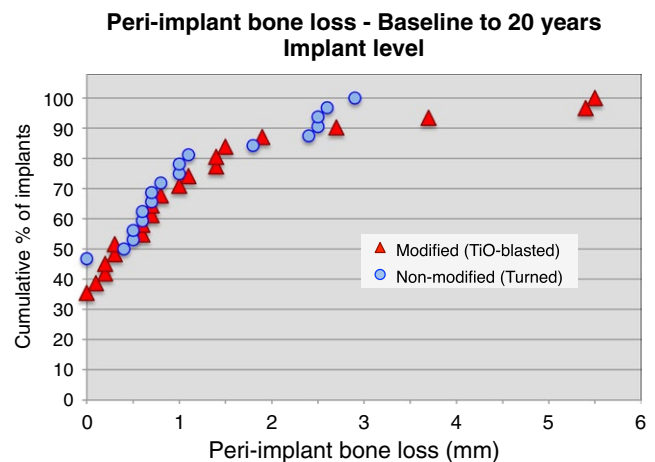


FIGURE 1 Cumulative distribution of implants with modified surface (TiO-blasted, $n = 32$) and non-modified surface (Turned, $n = 32$) according to *peri-implant bone loss* from baseline to the 20-year follow-up

4 | DISCUSSION

The present study reports on the 20-year outcome of a randomized controlled clinical trial with focus on whether implant surface modification may have an impact on the preservation of the peri-implant bone support. It was observed that the overall mean bone level change was small and amounted to only -0.8 and -0.4 mm for implants with a moderately-rough and a turned (non-modified) surface, respectively. About one-third of the implants with a moderately rough surface and 50% with a non-modified surface showed no radiographic bone loss after 20 years. It is suggested that increased implant surface roughness may not favor long-term preservation of the peri-implant marginal bone level.

The study is unique by presenting results from 20 years of follow-up of a RCT comparing marginal bone alterations at implants

with different surface characteristics in patients treated for moderate to advanced periodontitis. By randomization each of the inserted FPDs was supported by at least one of each of the two categories of implants. The benefit of this particular study design is that the influence on treatment outcome of various confounding factors is minimized. A critical point to consider in the evaluation of the present findings is that half of the originally included subjects were lost to the 20-year follow-up examination. The dominating reason for this decrease in the sample was a high mortality rate (37%) that in turn was related to a high mean age (60 years) at time of enrollment in the study. In a 12–15-year follow-up study on implant therapy in a Swedish patient sample with similar mean age at time of treatment, Raval, Dahlgren, Teiwik, and Gröndahl (2013) reported that deceased subjects accounted for 52% of the drop-outs. The corresponding figure in the current study with 20 years of follow-up was 73%. Together these observations highlight the inevitable risk of high drop-outs in long-term studies on implant therapy involving elderly subjects, which was the consequence in the present study due to the selection criteria of having been treated for moderate-advanced periodontitis and lost teeth due to the disease.

The mean peri-implant bone level change over the 20-years was small and no significant difference was observed between the two types of implants. Post-hoc analysis revealed that to detect a true difference in bone level change between implants types with a 80% of power and a type I error of 0.05, 73 implants in each group would have been required. Hence, while at baseline and at 5-year follow-up (Wennström et al., 2004) the number of implants included was sufficient for the comparison, at the 20-year follow-up the reduction in the original sample had diminished the power of detecting a significant difference between the two groups. It must be emphasized, however, that even if a statistical significance could have been confirmed, the observed difference of 0.4 mm in mean bone level change between groups after 20 years cannot be considered clinically relevant.

Recent systematic reviews (Doornierwaard et al., 2017; Esposito et al., 2014) provided limited evidence that the amount of longitudinal peri-implant marginal bone loss at implants with modified surfaces is greater than that at implants with a non-modified or minimally rough surface. In the current study two types of implants that differed only with respect to surface characteristics were compared; the TiOblast® surface implant with a Sa value of 1.1 µm (moderately rough) and the Turned surface implant with a Sa value of 0.7 µm (turned or minimally rough). The small amount of bone level change observed after 20 years documented that such a modest difference in Sa value had no significant influence on the bone level. This conclusion is supported by previous studies with 5–12 years of follow-up comparing bone level changes at TiO-blasted and turned AstraTech implants. From a 5-year RCT study Gotfredsen and Karlsson (2001) reported a mean bone loss of 0.5 mm for the moderately-rough TiO-blast® implant compared to 0.2 mm for the Turned implant category. In a 12 year prospective study Vroom et al. (2009) recorded an even smaller amount of longitudinal bone loss (0.1 mm)

and found no difference between the two types of implants. This particular study involved only full-mouth rehabilitation cases in the lower jaw and 90% of the subjects had no history of periodontitis. In contrast, the current study involved subjects susceptible to periodontitis and presented with a mean remaining periodontal bone support of about 44% of the root length (Wennström et al., 2004). Furthermore, the prosthetic rehabilitation was mostly performed in the posterior segments of the jaws. It is well-documented that susceptibility to periodontitis is associated with an increased risk of peri-implant marginal bone loss (Derks et al., 2016; Doornierwaard et al., 2017; Hardt, Gröndahl, Lekholm, & Wennström, 2002; Koldslund, Scheie, & Aass, 2011; Rocuzzo, De Angelis, Bonino, & Aglietta, 2010). However, Rocuzzo, Bonino, Dalmaso, and Aglietta (2014) also demonstrated that in periodontitis-susceptible patients carrying implant-supported reconstructions the risk of biological complications and peri-implant bone loss could be minimized by proper plaque control and regular supportive care. In agreement with this documentation, the current study showed that of the 26 implants that were without bone loss after 20 years, all but one were free of plaque, soft-tissue inflammation and deep pockets at both the 5- and 20-year examinations. Taken together the current findings and the observations by Rocuzzo et al. (2014) emphasize the critical issue of maintaining a proper level of professional and self-performed infection control for the prevention of peri-implant bone loss. Furthermore, the finding that about 40% of the implants showed no change in the peri-implant bone level over the 20 years clearly document that loss of bone support is not a natural and inevitable effect of time in function.

Based on the criteria for “overt peri-implantitis” as proposed by Koldslund, Scheie, and Aass (2010), i.e. bleeding on probing/suppurative and bone loss >2 mm, a total of 5 (20%) of the 25 patients who were available for examination at 20 years were diagnosed with or had been treated for this inflammatory condition. This figure falls within the upper range of corresponding data of 8%–20% that were reported in previous studies, but with shorter follow-up periods (Cecchinato, Parpaiola, & Lindhe, 2014; Derks et al., 2016; Koldslund et al., 2010; Roos-Jansåker, Lindahl, Renvert, & Renvert, 2006). That the prevalence of peri-implantitis is positively related to time in function of the implants was shown in a systematic review by Derks and Tomasi (2015). It must also be emphasized that the current patient sample was too small to allow any comparison with regard to the occurrence of peri-implantitis between implants with modified and non-modified surfaces.

A relevant issue to consider in relation to the rate of implant failures is the analysis of implant fractures. Seventeen implants (11.5%) in the present study were lost to the final follow-up due to fracture. This incidence is higher than data presented in literature reviews (Berglundh, Persson, & Klinge, 2002; Millen, Brägger, & Wittneben, 2015), which indicated that implant fracture is a rare complication; ranging from 0.94 to 1.46% in studies with a minimum follow-up of 3 years. Several factors may be implicated as contributing to implant fracture, e.g. implant location, number and dimension of implants supporting the prosthesis, inclusion of cantilevers,

height of supra-construction, excessive occlusal load, time in function (Shemtov-Yona, Rittel, Machtei, & Levin, 2014; Tabrizi, Behnia, Taherian, & Hesami, 2017; Zurdo, Romao, & Wennström, 2009). All implants used in the current study had a diameter of 3.5 mm and 50% of the FPDs were designed with a distal cantilever unit (Wennström et al., 2004). Furthermore, the patients had experienced pronounced bone loss due to periodontitis before the implants were placed and hence, the vertical dimension of the fixed prosthesis was pronounced. It is suggested that the co-existence of these factors by time (the majority of implant fractures occurred after 8 years in function) may have contributed to increased stress resulting in material fatigue.

In summary, for both non-modified and modified implants the overall degree of bone loss was minute over the 20-year observation period. The comparatively small difference in surface roughness between the two implant types did not influence the long-term peri-implant bone level change.

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CONFLICT OF INTEREST

The authors declare no potential conflicts of interest with respect to the authorship and/or publication of this article.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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