Long-Term Effect of Surface Roughness and Patients' Factors on Crestal Bone Loss at Dental Implants. A Systematic Review and Meta-Analysis

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ABSTRACT

Publications from 2011 to 2015 were selected to evaluate effect of implant surface roughness on long-term bone loss as surrogate for peri-implantitis risk. 87 out of 2,566 papers reported the mean bone loss after at least 5 years of function. Estimation of the proportion of implants with bone loss above 1, 2, and 3 mm as well as analysis the effect of implant surface roughness, smoking, and history of periodontitis was performed. By means of the provided statistical information of bone loss (mean and standard deviation) the prevalence of implants with bone loss ranging from 1 to 3 mm was estimated. The bone loss was used as a surrogate parameter for "peri-implantitis" given the fact that "peri-implantitis" prevalence was not reported in most studies or when reported, the diagnostic criteria were unclear or of dubious quality. The outcome of this review suggests that peri-implant bone loss around minimally rough implant systems was statistically significant less in comparison to the moderately rough and rough implant systems. No statistically significant difference was observed between moderately rough and rough implant systems. The studies that compared implants with comparable design and different surface roughness, showed less average peri-implant bone loss around the less rough surfaces in the meta-analysis. However, due to the heterogeneity of the papers and the multifactorial cause for bone loss, the impact of surface roughness alone seems rather limited and of minimal clinical importance. Irrespective of surface topography or implant brand, the average weighted implant survival rate was 97.3% after 5 years or more of loading. If considering 3 mm bone loss after at least 5 years to represent the presence of "peri-implantitis," less than 5% of the implants were affected. The meta-analysis indicated that periodontal history and smoking habits yielded more bone loss.

KEY WORDS: bone loss, dental implant, implant survival, meta-analysis, peri-implantitis, surface roughness, surface topography, systematic review

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INTRODUCTION

Today, achievement of osseointegration is no longer the only key issue in research related to oral implantology as the predictability of implant therapy is high due to improvements of biomaterials and clinical procedures. Multiple long-term studies show successful treatment outcomes in terms of functional rehabilitations with survival rates ranging from 89.5 to 99.2%.[1–6] Instead, the focus has shifted to peri-implant bone stability, which is paramount for long-term success. Bone loss may lead to complications such as soft tissue recession, "peri-implantitis," implant fractures, and eventually loss of the implant.

Although dental implants have demonstrated favorable long-term results,[7–12] failures do occur and can be related to different factors. For instance, early implant failures have been related to excessive surgical trauma, an impaired healing ability, premature loading, and infection. In addition, late failures are mostly attributed to occlusal overload and/or progressive peri-implant bone loss.[13] Most patients of today have lost one or a few teeth and have high demands on the esthetic outcome. Peri-implant bone stability is a prerequisite for soft tissue preservation and hence, bone loss may lead to soft tissue recession and a poor esthetic outcome.[14,15]

Likewise periodontitis, peri-implantitis is a multifactorial disease but associated with pathogens colonizing the subgingival biofilm, and the host response.[16] Peri-implant mucositis has been described as a reversible inflammation of the peri-implant soft-tissues without signs of loss of the supporting bone. Peri-implantitis is defined as inflammation of the soft tissues in combination with ongoing loss of the supporting peri-implant bone beyond the physiological bone adaptation.[17] The reasons for the inflammation is multifactorial and under debate and especially diagnostic thresholds or diagnostic methods in general, are currently leading to biased reports on peri-implantitis prevalences. Some authors look on "peri-implantitis" as a biofilm induced disease while others regard this as an imbalanced foreign body response. However, not every single implant presenting peri-implant bone loss can be defined as peri-implantitis. It is well documented that the initial bone loss is an inevitable reaction to surgery and loading and known clinically as the establishment of a soft tissue seal called "biologic width."[18–20]

Poor oral hygiene is known as an important risk factor in the development and progression of periodontal disease.[21] Poor oral hygiene initiates a persistent gingivitis, which results in a 46-times higher risk for tooth loss.[22] Similarly, there is evidence that good oral hygiene should be recommended to prevent bleeding and pocket formation around implants.[23] Patient less compliant with maintenance are also more prone to implant failure.[24]

Different systematic reviews have shown that patients with existing or ongoing periodontitis are more likely to experience implant failure and biological complications.[25–32] This could be related to the type of microbiotia in these patients and the ability of forming biofilms. It could also reflect a stronger immunological response to foreign bodies such as biofilm, plaque, and implant components. However, it is difficult to draw strong conclusions due to the high heterogeneity among the studies and methodological variability.[33]

Tobacco smoke contains nearly 4,000 chemicals such as carbon monoxide, hydrogen cyanide, reactive oxidizing radicals. Some of those chemicals are known to be toxic and as a consequence smoking harms nearly every organ in the body including the tissues within the oral cavity. The negative effect of smoking is attributed to the impaired vascularity of the periodontal tissues rather than a vasoconstrictive effect.[34] By affecting the revascularization it may lead to an impaired healing after surgery. Different systematic review identified smoking as a factor affecting implant survival and peri-implant bone loss.[27,35,36] Additionally, Lindquist and colleagues identified smoking the predominant factor affecting peri-implant bone loss. However, good oral hygiene reduced the perniciuous effects of smoking while poor oral hygiene aggravated bone resorption.[37]

Besides, the above-mentioned patient-related factors, implant-related factors can possibly influence implant treatment outcome. Today, most marketed implant surfaces are moderately rough with S_a values between 1.1 and 2 μm. A brief overview of various surface roughness for some implant brands is given in Table 1. Increasing implant surface roughness, induces qualitative and quantitative changes in biofilm formation.[38] Quirynen and colleagues suggested that implants with increased surface roughness may be more prone to peri-implant bone loss

TABLE 1 Surface Roughness and Corresponding Sa Values (μm) and Some Implant Brands

Surface roughness	Sa value	Some implant brands
Smooth	$< 0.5\ \mu m$	Experimental not clinically available
Minimally rough	$0.5–1\ \mu m$	Machined Brånemark implants, Osseotite, Nanotite
Moderately rough	$> 1–2\ \mu m$	SLA, TiUnite, Osseospeed, TiOblast, Southern
Rough	$> 2\ \mu m$	IMZ, TPS, Ankylos, Friadent, Xive

and consequently, late implant failure.[28] Conversely, Chappuis and colleagues showed that even rough TPS-coated implants can be very successful presenting very limited peri-implant bone loss after 20 years follow-up in a well-maintained population.[39] One can conclude that the literature is inconclusive about the effect of implant surface roughness on implant success.

Hence the aim of this study was to scrutinize whether long-term peri-implant bone loss, beyond physiologic bone adaptation, is affected by implant surface roughness and/or patient-related factors such as smoking and history of periodontitis.

MATERIALS AND METHODS

Paper Selection

Since it was the aim of the paper to assess long-term bone loss as surrogate variable for peri-implantitis and to scrutinize the type of studies and the level of quality of reporting, it was decided to conduct a broad literature search using the Pubmed database of the US National Library of Medicine for articles. Publications from 2011 up to December 24, 2015 were selected using the general search algorithm: ((((((“bone loss”) OR “peri-implantitis”)) OR “peri implant”)) AND dental implant). It was opted not to perform a strict review using the terminology “Peri-Implantitis” [Mesh] as search criterion due to the limitation of the generated output to only 426 papers. Because most surface-modified implants were launched commercially at the time of the millennium change, the time frame was set to 2011 to 2015 because this increased the probability to select predominantly currently commercially available implant brands and various rather new surfaces. Furthermore, it seemed logical to have a literature search cut-off at 2011 because peri-implantitis is reported after longer follow-up times and the scientific community has taken special interest in clinical research on peri-implantitis after consensus meetings with specific guidelines for research from 2006 onwards.[40–43]

The list of generated articles was obtained through elimination based on the title and detailed information given in the abstract. Further evaluation and refining of the selected papers was performed by reading the papers and registering the described results in the data set. In case of disagreement over the inclusion/exclusion, both evaluators (RD & VC) discussed and reached a consensus or, in case of further doubt, a third evaluator was consulted (HDB).

To be included in the study, the papers had to be published in English, report on bone loss compared to a baseline measurement and include at least 10 patients after a minimal mean follow-up time of 5 years. Only studies discussing straightforward implant treatment in systemically healthy patients, as the test strategies were included. Hence, studies describing implant treatments in tumor-resected areas, studies involving extensive bone grafts or zygomatic implants were excluded. Exceptional, experimental or uncommon implant designs, as well as implants with unknown surface topography, were excluded. Studies were additionally rejected when statistical evaluation was hampered because of incomplete data reporting, such as lacking failure rate, implant or patient numbers, bone loss and standard deviation calculated on implant level. However, studies lacking standard deviation on bone loss were included for calculating implant survival.

Table 2 gives an overview of exclusion criteria and the references of the excluded papers. The review did not exclude studies with smokers, patients with periodontal history, controlled diabetes, or implants in sinus lifted bone. These procedures are today considered part of daily good clinical practice. To avoid a biased selection and to ensure that the papers reflected the daily clinical situation, no distinction was made based on study design (prospective or

TABLE 2 Excluded Papers and Exclusion Reason

Follow-up <5 years	
Kan and colleagues[44]	2011
Lopez-Piriz[45]	2012
Soardi and colleagues[46]	2012
Paul and colleagues[47]	2013
Dagorne and colleagues[48]	2014
Ata-Ali and colleagues[49]	2015
Jervoe-Storm and colleagues[50]	2015
<10 patients per treatment group at baseline	
Zafiropoulos and colleagues[51]	2013
Romanos and colleagues[52]	2013
<10 patients per treatment group after at least 5 years	
Vanlioglu and colleagues[53]	2012
Bahat and colleagues[54]	2012
Romeo and colleagues[55]	2014
Incomplete data about bone loss after at least 5 years	
Cortellini and colleagues[56]	2011
Ozkan and colleagues[57]	2011
Ozkan and colleagues[58]	2011
Akoglu and colleagues[59]	2011
Stacchi and colleagues[60]	2012
Maló and colleagues[61]	2012
Fugazzotto[62]	2012
Swierkot and colleagues[63]	2012
Degidi and colleagues[64]	2012
Ormianer and colleagues[65]	2012
Rocci and colleagues[66]	2012
Covani and colleagues[67]	2012
Wilson and colleagues[68]	2013
Harel and colleagues[69]	2013
Romanos and colleagues[70]	2013
Harel and colleagues[71]	2013
Canullo and colleagues[72]	2016
Felice and colleagues[73]	2014
Frisch and colleagues[74]	2014
Woelber and colleagues[75]	2016
Maló and colleagues[76]	2015
Trullenque-Eriksson and colleagues[77]	2015
Jemt and colleagues[78]	2015
Melo and colleagues[79]	2015
Incomplete data about number of patients and/or implants	
Yaltirik and colleagues[80]	2011
Ueda and colleagues[81]	2011
Stoker and colleagues[82]	2012
Krennmair and colleagues[83]	2011
Oliva and colleagues[84]	2012
Moeintaghavi and colleagues[85]	2012
Follow-up <5 years	
Pettersson and colleagues[86]	2015
Sivolella and colleagues[87]	2013
Berberi and colleagues[88]	2014
Mangano and colleagues[89]	2014
Rossi and colleagues[90]	2015
Vázquez Alvarez and colleagues[91]	2014
Nack and colleagues[92]	2015
Korfage and colleagues[93]	2014
Cavalli and colleagues[94]	2015
Maló and colleagues[95]	2014
Anitua and colleagues[96]	2016
Ebinger and colleagues[97]	2016
Jeong and colleagues[98]	2015
Konstantinidis and colleagues[99]	2015
Fretwurst and colleagues[100]	2015
Krebs and colleagues[101]	2015
Quaranta and colleagues[102]	2015
Rossi and colleagues[103]	2016
Incomplete data about follow-up time	
Mijiritsky and colleagues[104]	2013
Zirconia implants	
Grassi and colleagues[105]	2015
Autologous onlay grafted bone	
Dasmah and colleagues[106]	2013
De Bruyn and colleagues[107]	2013
Sbordone and colleagues[108]	2012
Stellingsma and colleagues[109]	2014
Duttenhoefer and colleagues[110]	2015
Patients treated with implants after oral tumors	
Zou and colleagues[111]	2015
No consensus about bone loss	
Hjalmarsson and colleagues[112]	2011

retrospective) or surgical or prosthetic treatment protocol.

Statistical Analysis

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 of bone loss and to estimate the proportion of implants with bone loss above 1, 2, and 3 mm. Analysis was performed additionally per implant surface roughness group and qualified as minimally rough, moderately rough, rough, or mixed/unknown. The latter included studies with unspecified implant surface roughness or where data were presented without making distinction between implant brands or surface topography.

For the descriptive statistics the results of the individual studies were weighted by the number of implants to prevent studies with extremely homogenous groups dominating the results. After the descriptive followed the assessment of the inter study variability. Preliminary analysis performed showed that the multitude of intervening factors jeopardized the successful reduction of the intra study variability by means of a meta-regression. As argument to sustain this statement the heterogeneity estimates of the random effects model were included and the results of meta-regression models predicting mean bone loss through mediating factors, such as smoking and roughness were presented. The aim of meta-analysis is the recombination of results of several studies through increased power and to detect influences that otherwise would appear to be statistically insignificant. Extreme heterogeneity of the studies does not allow for the straightforward application of meta-analytic statistics and testing strategies. Therefore, a subgroup analysis was conducted for roughness, smoking, and periodontal history based on studies that allowed for "paired" comparisons. Null-hypotheses were the equality of bone loss between minimally rough and moderately rough implant surfaces, smokers and non-smokers, and healthy patients and patients with a periodontal history, respectively. Throughout the meta-analytic analysis the study results are weighted by the inverse of the variance of the effect sizes. Heterogeneity was considered to be high if I^2 exceeded 70%, between 50% and 70% the heterogeneity was considered to be medium, and below 50% small. When the heterogeneity was revealed to be statistically significant ($p < .05$) the random effects model was interpreted. If not significant, the fixed model was evaluated.

Descriptive statistics and the recombination of results were performed using MatLab R2015b version (8.6.0.267246) (The MathWorks, Inc., Natick, MA, USA). The meta-regression and fixed and random effects modeling were performed using the statistical package R version 3.1.0 (2014-04-10) (The R foundation for Statistical Computing), platform: x86_64-w64-mingw32/x64 (64-bit) with "metaphor" package (version 1.9-7) for meta-regressions and the package "meta" version 4.3-2 for random and fixed effect modeling.

RESULTS

Selection of Papers

The literature search yielded 6,445 studies starting in 1972 up to 2015. Of the last 2,566 publications between 2011 and August 14, 2015, in total 156 were deemed appropriate and selected by the two examiners taking the initial selection criteria into account. A further selection after reading of the paper disqualified another 69 papers for several reasons, among others the lack of standard deviation on bone loss. This was an essential factor to allow statistical estimation of the proportion of implants with an arbitrarily selected threshold for bone loss (Table 2).

Quality of the Papers

The paper search revealed in total 87 included studies (summarized in Table 3) that reported a mean bone loss on implant level over a 5 to 20 year follow-up time; 48 were prospective and 39 were retrospective. Some papers compared different treatment protocols which were considered as separate study groups for the statistical analysis of implant survival or bone loss calculation because some pertained to different surface or implant types as well as different treatment protocols. In the 123 treatment groups in total 15,695 implants were inserted in 6,755 patients and information about mean bone loss at the last examination visit was available from 13,970 implants after at least 5 years of implant function. The total drop-out of implants from baseline to the evaluation time point was 11% for the 87 selected papers.

Fifty-three out of 87 studies pertained to 10,533 originally placed implants from the portfolio of the three world leading companies Dentsply, Nobel Biocare and Straumann representing proportionally 67.1% from the total material. With 9,136/10,533 initially placed implants remaining at follow-up, the dropout rate was 13.3%.

Information on probing depth and bleeding on probing was available in only 40 and 49 of the included studies, respectively. Twenty-seven out of 87 papers reported peri-implantitis prevalence on implant level (Table 4) ranging between 0% and 39.7%. This large range can be explained by the arbitrarily chosen thresholds and diagnostic parameters for disease. The cut-off bone loss for peri-implantitis ranged from 1 to 3 mm and the cut-off probing

TABLE 3 Overview of Finally Included Papers with Study Design (P = prospective; R = retrospective), Mean Follow-Up (years), Number of Patients and Implants at Baseline, Implants at Follow-Up, Mean Implant Bone Loss (mm) and Standard Deviation, Implant Survival Rate (%) and Surface Roughness (1= unknown or mixture of surfaces, 2= smooth, 3= moderately rough, 4= rough)

Author	Year	Study design	Treatment subgroups	Mean follow-up years	Patients at baseline	Implants at baseline	Implants at follow-up	Implant brand	Surface	Baseline radiograph time	Mean implant bone loss (mm)	Standard deviation bone loss (mm)	Implant survival rate %	Surface roughness
Becker and colleagues[113]	2016	P		6.5	31	84	40	Nobel Biocare	Mixed	1	−0.10		94.60%	Mixed
Imburgia & Del Fabbro[114]	2015	R		8.8	41	205	205	Nobel Biocare	TiUnite	0	0.43	1.15	96.10%	3
Hoeksema and colleagues[115]	2016	P	1: Older patients	10		106	64	Straumann	TPS	1	1.20	1.20	93.40%	4
			2: Young patients	10	105	104	99	Straumann	TPS	1	1.20	1.10	97.10%	4
Vandeweghe and colleagues[116]	2016a	R		7.5	46	211	211	Southern	Mod rough	0	1.17	0.49	99.50%	3
Vandeweghe and colleagues[117]	2016b	R	1: Moderately rough	14.3		121	121	Southern	Mod rough	0	1.73	1.54	97.00%	3
			2: Smooth	14.3	33	76	76	Southern	Machined	0	1.41	0.92		2
Nedir and colleagues[118]	2016	P		10	17	25	23	Straumann	SLA	0	1.00	0.90	100.00%	3
Park and colleagues[119]	2015	R		10	74	242	242	Implantium Dental Implant	Moderately rough	0	0.28	0.78	97.90%	3
Eerdekens and colleagues[120]	2015	P		5	10	60	10	Ankylos	Ankylos	1	0.60	1.12	96.70%	4
Perrotti and colleagues[121]	2015	P	1: Tuberplant	10	97	67	67	Oralplant	TPSS	1	1.31	0.74	98.60%	4
			2: Bioplant	10		59	59	Oralplant	TPSS	1	0.74	0.92	100.00%	4
Romanos and colleagues[122]	2016	P	1: Immediate loading	10.1	12	30	30	Ankylos	Ankylos	9	0.57	1.06	100.00%	4
			2: Delayed loading	10.4		30	30	Ankylos	Ankylos	9	1.12	1.30	100.00%	4
Zhao and colleagues[123]	2016	R		6.2	45	45	45	Straumann	SLA	1	1.10	0.92	100.00%	3
Crespi and colleagues[124]	2014	P	1: Screw retained	8	28	136	136	Outlink	TPS	0	0.42		98.50%	4
			2: Cement retained	8		136	136	Outlink	TPS	0	0.67		100.00%	4
van Velzen and colleagues[125]	2015	P		10	250	506	367	Straumann	SLA	0	1.21	0.94	99.70%	3
Trullenque-Eriksson & Guisado-Moya[126]	2014	R		13.19	105	342	342	Mixed	Mixed	1	1.84	1.35	90.60%	Mixed
Joda and colleagues[127]	2015	R		5	98	316	316	Ankylos	Ankylos	1	1.02	1.25	97.20%	4
Meijer and colleagues[128]	2014	P		10	150	240	240	Mixed	Mixed	1	1.10	1.10	95.30%	Mixed

Table 3. *cont.*

Author	Year	Study design	Treatment subgroups	Mean follow-up years	Patients at baseline	Implants at baseline	Implants at follow-up	Implant brand	Surface	Baseline radiograph time	Mean implant bone loss (mm)	Standard deviation bone loss (mm)	Implant survival rate %	Surface roughness
Slotte and colleagues[129]	2015	P		5	32	86	71	Straumann	SLA	1	0.53	0.34	92.20%	3
Schropp and colleagues[130]	2014	P		10	72	63	47	Biomet/3I	Osseotite	0	0.67	0.98	unknown	2
Gholami and colleagues[131]	2014	P	1: Partial cases	5	20	35	23	Thommen	Moderately rough	0	1.10	0.60	98.40%	3
			2: Full cases	5		23	35	Thommen	Moderately rough	0	1.50	0.90		3
Cooper and colleagues[132]	2014a	P		5	19	23	18	Astra Tech	Osseospeed	0	0.18	0.79	96.50%	3
Vervaeke and colleagues[133]	2016	P		9	50	320	245	Astra Tech	TiOblast	0	1.68	2.08	99.20%	3
Mangano and colleagues[134]	2015	R		20	49	178	178	Mac System	Unknown	1	1.80	0.60	97.20%	Unknown
Simion and colleagues[135]	2015	R		12	29	59	59	Nobel Biocare	Machined	1	1.34	0.79	93.20%	2
Tealdo and colleagues[136]	2014	P	1: Immediate loading	6.2	49	163	159	Unknown	Rough	0	1.12	1.12	93.90%	4
			2: Delayed loading	6.2		97	90	Unknown	Rough	0	1.94	1.44	95.90%	4
Covani and colleagues[137]	2014	P		5	47	47	45	Khono Implants	Unknown	0	1.08	0.43	95.70%	Unknown
Cooper and colleagues[138]	2014b	P	1: Immediate placement	5	113	55	55	Astra Tech	Osseospeed	0	0.43	0.63	95.00%	3
			2: Delayed placement	5		58	58	Astra Tech	Osseospeed	0	0.38	0.62	98.00%	3
Leventi and colleagues[139]	2014	R		7.7	41	102	102	Calcitek	Calcitek	0	1.28	1.06	99.00%	4
Meyle and colleagues[140]	2014	P		10	20	54	54	Frialit	Friadent	1	0.60	0.26	96.30%	4
Pozzi and colleagues[141]	2014	R		8.82	73	167	160	Nobel Biocare	TiUnite	0	1.58	1.61	100.00%	3
Anitua and colleagues[142]	2014	R		10.3	75	111	87	BTI	Unknown	0	0.95	0.65	98.90%	Unknown
Rasperini and colleagues[143]	2014	R	1: Periodontally compromised non smoking	10	120	20	20	Nobel Biocare	Machined	1	2.32	0.41	95.00%	2
			2: Periodontally compromised smoking	10		10	10	Nobel Biocare	Machined	1	3.47	1.09	90.00%	2

Table 3. *cont.*

Author	Year	Study design	Treatment subgroups	Mean follow-up years	Patients at baseline	Implants at baseline	Implants at follow-up	Implant brand	Surface	Baseline radiograph time	Mean implant bone loss (mm)	Standard deviation bone loss (mm)	Implant survival rate %	Surface roughness
			3: Periodontally compromised non smoking	10		20	20	Straumann	TPS	1	2.32	0.41	85.00%	4
			4: Periodontally compromised smoking	10		10	10	Straumann	TPS	1	3.77	1.43	80.00%	4
			5: Periodontally healthy non smoking	10		20	20	Nobel Biocare	Machined	1	1.43	0.38	95.00%	2
			6: Periodontally healthy smoking	10		10	10	Nobel Biocare	Machined	1	2.65	0.41	90.00%	2
			7: Periodontally healthy non smoking	10		20	20	Straumann	TPS	1	1.95	0.42	95.00%	4
			8: Periodontally healthy smoking	10		10	10	Straumann	TPS	1	2.51	0.31	100.00%	4
Mozzati and colleagues[144]	2015	R		11	90	209	168	Nobel Biocare	TiUnite	0	0.60	1.17	97.10%	3
Zou and colleagues[145]	2013	R	1: Telescopic overdenture	8	44	112	106	Straumann	TPS	9	1.30	0.40	100.00%	4
			2: Bar overdenture	8		105	95	Straumann	TPS	9	1.20	0.60	100.00%	4
Donati and colleagues[146]	2015	P		5	151	161	140	Astra Tech	Osseospeed	0	0.32	1.15	95.60%	3
Rocci and colleagues[147]	2013	P	1: TiUnite	9	44	66	51	Nobel Biocare	TiUnite	0	1.40		95.50%	3
			2: Machined	9		55	39	Nobel Biocare	Machined	0	1.70		85.50%	2
Dhima and colleagues[148]	2013	R		9	81	81	81	Nobel Biocare	TiUnite	0	−0.94	0.99	100.00%	2
Krennmair and colleagues[149]	2013	R		5.5	42	152	152	Camlog	Camlog	0	1.21	0.36	100.00%	3
Akca and colleagues[150]	2013	R	1: Ball abutment overdenture	5	29	38	38	Straumann	SLA	9	0.77	0.31	97.00%	3
			2: Locator abutment overdenture	5		20	20	Straumann	SLA	9	0.59	0.13	100.00%	3
Gelb and colleagues[151]	2013	R		7.33	57	107	107	Nobel Biocare	TiUnite	0	1.49	1.03	100.00%	3

Table 3. *cont.*

Author	Year	Study design	Treatment subgroups	Mean follow-up years	Patients at baseline	Implants at baseline	Implants at follow-up	Implant brand	Surface	Baseline radiograph time	Mean implant bone loss (mm)	Standard deviation bone loss (mm)	Implant survival rate %	Surface roughness
Schwarz and colleagues[152]	2014	P		7.2	37	185	126	Frialoc system	Frialit	0	1.10	1.20	89.20%	4
Wagenberg and colleagues[153]	2013	R		10.18	541	1,187	1,181	Nobel Biocare	Machined	0	0.52	0.79	99.62%	2
Chappuis and colleagues[39]	2013	R		20	67	95	85	Straumann	TPS	0	0.14	1.09	89.50%	4
Sayardoust and colleagues[154]	2013	R	1: Smokers, TiUnite	5	80	56	56	Nobel Biocare	TiUnite	1	1.16	1.80	92.90%	3
			2: Never smokers, TiUnite	5		52	52	Nobel Biocare	TiUnite	1	1.26	1.08		3
			3: Smokers, Machined	5		78	78	Nobel Biocare	Machined	1	1.54	1.85		2
			4: Never smokers, Machined	5		66	66	Nobel Biocare	Machined	1	0.84	1.14		2
Calvo-Guirado and colleagues[155]	2014	P		10	64	86	86	Biomet/3I	Osseotite	0	1.01	0.22	97.10%	2
Lops and colleagues[156]	2013	P	1: Titanium abutment	6	85	47	47	Astra Tech	TiOblast	1	0.50	0.30	100.00%	3
			2: Zirconium abutment	6		38	38	Astra Tech	TiOblast	1	0.40	0.20	100.00%	3
Dam and colleagues[157]	2014	P		5.5	174	378	378	Straumann	Mixed	0	1.12	1.10	Unknown	Mixed
Buser and colleagues[158]	2013	P		7	41	41	41	Straumann	SLA	0	0.38	0.72	100.00%	3
Lee and colleagues[159]	2012	R		5.7	175	116	259	Mixed	Mixed	9	0.93	0.15	Unknown	?
Nickenig and colleagues[160]	2013	P	1: Non polished collar	5.2	34	70	70	Nobel Biocare	TiUnite	0	0.70		Unknown	3
			2: Polished collar	5.2		63	63	Nobel Biocare	TiUnite	0	1.40			3
Kokovic and colleagues[161]	2014	P	1: Immediate loading	5	12	36	36	Straumann	SLA	0	0.40	0.24	100.00%	3
			2: Early loading	5		36	36	Straumann	SLA	0	0.80	0.19	100.00%	3
Mertens and colleagues[162]	2012	R		10.1	14	52	52	Astra Tech	TiOblast	1	0.30	0.50	100.00%	3
Renvert and colleagues[163]	2012	R	1: TiOblast	13	41	80	80	Astra Tech	TiOblast	1	0.80		Unknown	3
			2: TiUnite	13		84	84	Nobel Biocare	TiUnite	1	1.00		Unknown	3
Mordenfeld and colleagues[164]	2014	P		10.2	20	53	53	Nobel Biocare	Machined	1	1.60	1.00	86.00%	2

Table 3. *cont.*

Author	Year	Study design	Treatment subgroups	Mean follow-up years	Patients at baseline	Implants at baseline	Implants at follow-up	Implant brand	Surface	Baseline radiograph time	Mean implant bone loss (mm)	Standard deviation bone loss (mm)	Implant survival rate %	Surface roughness
Mir-Mari and colleagues[165]	2012	R		6.7	68	217	217	Nobel Biocare	Machined	1	0.26		Unknown	2
Horwitz and colleagues[166]	2012	P		5	19	74	39	MIS implant technologies	Moderately rough	0	1.41	0.67	Unknown	3
Deporter and colleagues[167]	2014	P		20	52	53	53	SPS dental implants	Rough	9	0.67		73.40%	4
Dierens and colleagues[168]	2013	R		18.5	53	62	59	Nobel Biocare	Machined	1	0.82	1.45	91.50%	2
Buser and colleagues[169]	2012	R		10	303	511	511	Straumann	SLA	0	1.52	0.66	98.80%	3
Frisch and colleagues[170]	2013	R		14.1	22	89	89	Nobel Biocare	Mixed	1	1.80	1.50	98.90%	Mixed
Camargos and colleagues[171]	2012	R		5	44	73	70	Unknown	Unknown	0	1.80		95.90%	Unknown
Lops and colleagues[172]	2012	P		13.2	121	108	207	Straumann	TPS	1	1.85	1.55	92.30%	4
Ormianer[173]	2012	R		10	46	108	172	Zimmer Dental	Unknown	9	0.18		99.00%	Unknown
Lang and colleagues[174]	2014	P		5	20	20	15	Zimmer Dental	Unknown	0	0.70	0.26	94.00%	Unknown
Ravald and colleagues[175]	2013	P	1: TiOblast	5	66	184	170	Astra Tech	TiOblast	0	0.70		95.00%	3
			2: Machined	5		187	175	Nobel Biocare	Machined	0	0.40		94.70%	2
Deporter and colleagues[176]	2012	P		10	24	48	30	Mixed	Moderately rough	9	1.20		95.50%	3
Jungner and colleagues[177]	2014	R	1: TiUnite	6.8		154	154	Nobel Biocare	TiUnite	9	2.00	0.90	99.40%	3
			2: Machined	6.8	103	133	133	Nobel Biocare	Machined	9	1.80	0.80	94.70%	2
Francetti and colleagues[178]	2014	P		6	22	54	49	Nobel Replace	TiUnite	0	0.76	0.47	97.96%	3
Ostman and colleagues[179]	2012	P		10	46	121	106	Nobel Biocare	TiUnite	0	0.70	1.35	99.20%	3
Arnhart and colleagues[180]	2013	R	1: TiUnite	6.7	47	136	136	Nobel Biocare	TiUnite	1	1.53	0.25	98.53%	3
			2: Machined	8.2		52	52	Nobel Biocare	Machined	1	2.42	0.34	96.15%	2
Lai et el.[181]	2013	R		10	168	231	231	Straumann	SLA	0	0.63	0.68	98.30%	3
Hayacibara and colleagues[182]	2013	R		8	71	74	74	Straumann	TPS	0	1		100.00%	4
Degidi and colleagues[183]	2012	P	1: Delayed placement	10	48	84	84	Nobel Biocare	TiUnite	0	1.93	0.40	98.05%	3
			2: Immediate placement	10		74	74	Nobel Biocare	TiUnite	0	1.98	0.37	96.52%	3

Table 3. *cont.*

Author	Year	Study design	Treatment subgroups	Mean follow-up years	Patients at baseline	Implants at baseline	Implants at follow-up	Implant brand	Surface	Baseline radiograph time	Mean implant bone loss (mm)	Standard deviation bone loss (mm)	Implant survival rate %	Surface roughness
Levine and colleagues[184]	2012	P		5	20	21	21	Straumann	SLA	0	0.58		100.00%	3
Rodrigo and colleagues[185]	2012	P	1: Immediate placement	5	22	34	26	Straumann	SLA	1	2.20	0.90	Unknown	3
			2: Delayed placement	5		34	26	Straumann	SLA	1	2.10	1.00	Unknown	3
Heschl and colleagues[186]	2012	P		10	30	30	120	Xive	Xive	1	1.80	0.65	98.30%	4
Lethaus and colleagues[187]	2011	P		5	14	60	54	Straumann	SLA	1	0.77	0.66	96.70%	3
Heschl and colleagues[188]	2013	P		5	39	156	152	Xive	Xive	0	1.44	0.78	99.40%	4
Browaeys and colleagues[189]	2013	R		5	83	501	106	Biomet/3I	Osseotite	0	1.57	1.10	92.10%	2
Turkyilmaz and colleagues[190]	2012	P	1: Early loading	7	26	24	24	Nobel Biocare	TiUnite	0	1.29	0.20	100.00%	3
			2: Delayed loading	7		24	24	Nobel Biocare	TiUnite	0	1.33	0.20	100.00%	3
Glauser and colleagues[191]	2013	P		7	38	102	73	Nobel Biocare	TiUnite	0	1.51	1.00	97.10%	3
Soardi and colleagues[192]	2013	R		5	538	376	376	Unknown	Unknown	0	1.98		94.90%	Unknown
Calvo-Guirado and colleagues[193]	2011	P		5	64	86	83	Certain Prevail 3i	Osseotite	0	0.97	0.39	97.10%	2
Kowar and colleagues[194]	2013	R	1: Completely edentulous maxilla	5	264	447	162	Nobel Biocare	Mixed	1	0.60	0.46	94.90%	Mixed
			2: Completely edentulous mandible	5		644	219	Nobel Biocare	Mixed	1	0.60	0.47	100.00%	Mixed
			3: Partially edentulous maxilla	5		146	78	Nobel Biocare	Mixed	1	0.60	0.47	97.60%	Mixed
			4: Partially edentulous mandible	5		119	69	Nobel Biocare	Mixed	1	0.40	0.50	100.00%	Mixed
Geckili and colleagues[195]	2011	R		5	71	159	159	Mixed	Mixed	1	0.99		98.74%	Mixed
Cochran and colleagues[196]	2011	P		5	200	626	542	Straumann	TPS	1	0.18	0.88	99.40%	4
Mertens and colleagues[197]	2011	P		8	17	106	99	Astra Tech	TiOblast	1	0.30	0.72	99.00%	3

Table 3. *cont.*

Author	Year	Study design	Treatment subgroups	Mean follow-up years	Patients at baseline	Implants at baseline	Implants at follow-up	Implant brand	Surface	Baseline radiograph time	Mean implant bone loss (mm)	Standard deviation bone loss (mm)	Implant survival rate %	Surface roughness
Roccuzzo and colleagues[198]	2012	P	1: Periodontally healthy	10	112	61	59	Straumann	TPS	0	0.75	0.88	96.60%	4
			2: Moderately periodontally compromised	10		95	88	Straumann	TPS	0	1.14	1.11	92.70%	4
			3: Severely periodontally compromised	10		90	81	Straumann	TPS	0	0.98	1.22	90.00%	4

pocket depth ranged from 4 to 6 mm. However, only 19/27 papers reported bleeding on probing, 16/27 reported probing depth, and only 11/27 actually defined peri-implantitis.

Implant Survival

From the 87 included papers and 123 study groups, the survival was reported in 79 papers and 107 study groups and ranged between 73.4% and 100%. Figure 1, A–C summarizes the implant survival rate and corresponding function time for the three surface roughness groups. In 44% of the studies the implant survival rate was between 95% and 100%, in half of the studies the survival ranged between 90% and 94.9%. Only in 6% of the studies the survival was below 90% with 73.4% survival after 20 years being the lowest one with a porous titanium alloy implant having a rough surface.[167] The average weighted implant survival was 97.3% including all studies and 96.4% for rough (Figure 1A), 98.4% for moderately rough (Figure 1B), and 97.6% for minimally rough (Figure 1C).

Bone Loss and Surface Roughness

Of the 123 treatment groups, 21 treatment groups were treated with a minimally rough implant surface (0.5–1 μm), 52 treatment groups with a moderately rough implant surface (1–2 μm), and 31 treatment groups with a rough implant surface (>2 μm); 19 groups reported a mixture of implants or did not report the surface. There were no studies with smooth surfaces available because these were merely experimental surfaces not used in the clinic.

Implant roughness and/or implant system were not reported or unknown and hence all these studies/treatment groups were considered as a separate group.[134,137,142,171,174,192] Some papers presented in their results a mixture of implants with various surface roughnesses and did not make specific distinction between them and therefore were also excluded for the detailed roughness versus bone loss evaluation.[113,126,128,157,159,170,193–195] Additionally, studies which did not mention the standard deviation of bone loss were excluded because calculation of proportions of bone loss was impossible.[124,147,160,163,165,167,171,175,176,182]

Figure 2, A–C summarize the bone loss in relation to the follow-up time including all 87 studies of this review. The overall mean bone loss was 1.01 mm

TABLE 4 Studies Discussing Mean Bone Loss (expressed as positive value in mm) and Standard Deviation, Survival Rate (%), Mean Probing Pocket Depth (mm), Bleeding on Probing (%) and Self-Reported Peri-Implantitis Prevalence

Author	Mean bone loss (SD)	Survival rate	Mean probing pocket depth (mm)	BoP	Prevalence peri-implantitis
Vandeweghe and colleagues 2016b[117]	1.41 (0.92)	97.00%	3.64		4.10%
Nedir and colleagues 2016[118]	1.00 (0.90)	100.00%	–		8.70%
van Velzen and colleagues 2015[125]	1.21 (0.94)	99.70%	3.71		7.00%
Trullenque & Guisado 2014[126]	1.84 (1.35)	90.60%	–		21.00%
Meijer and colleagues 2014[128]	1.10 (1.10)	95.30%	3.4		20.30%
Schropp and colleagues 2014[130]	0.67 (0.98)	–	–	70.00%	4.30%
Mangano and colleagues 2015[134]	1.80 (0.60)	97.20%	–		1.10%
Simion and colleagues 2015[135]	1.34 (0.79)	93.20%	2.9	54.00%	0.00%
Meyle and colleagues 2014[140]	0.60 (0.26)	96.30%	3.3	27.00%	23.80%
Anitua and colleagues 2014[142]	0.95 (0.65)	98.90%	–		0.90%
Donati and colleagues 2015[146]	0.32 (1.15)	95.60%	–	13.00%	2.90%
Gelb and colleagues 2013[151]	1.49 (1.03)	100.00%	–	4.70%	0.00%
Schwarz and colleagues 2014[152]	1.10 (1.20)	89.20%	–	60.00%	4.30%
Chappuis and colleagues 2013[39]	0.14 (1.09)	89.50%	3.14		6.30%
Renvert and colleagues 2012[163]	0.80 (-)	–	–	80.00%	32.10%
	1.00 (-)	–	–	94.00%	39.70%
Frisch and colleagues 2013[170]	1.80 (1.50)	98.90%	3.13	21.00%	8.00%
Camargos and colleagues 2012[171]	1.80 (-)	95.90%	2.3	59.00%	4.30%
Lops and colleagues 2012[172]	1.85 (1.55)	92.30%	2.3		8.30%
Ormianer and colleagues 2012[173]	0.18 (-)	99.00%	–		2.30%
Ravald and colleagues 2013[175]	0.70 (-)	95.00%	–		6.00%
	0.40 (-)	94.70%	–		5.00%
Jungner and colleagues 2014[177]	2.00 (0.90)	99.40%	1.8		1.80%
Ostman and colleagues 2012[179]	0.70 (1.35)	99.20%	–	9.20%	1.00%
Arnhart and colleagues2013[180]	2.42 (0.34)	96.20%	2.86	23.20%	1.90%
Lai and colleagues 2013[181]	0.63 (0.68)	98.30%	–		2.00%
Levine and colleagues 2012[184]	0.58 (-)	100.00%	–		0.00%
Rodrigo and colleagues 2012[185]	2.20 (0.90)	–	–	14.20%	8.80%
	2.10 (1.00)	–	–	13.70%	2.90%
Roccuzzo and colleagues2012[198]	0.75 (0.88)	96.60%	3.1	12.00%	4.70%
	1.14 (1.11)	92.70%	3.5	31.00%	11.20%
	0.98 (1.22)	90.00%	3.9	31.00%	15.10%

(95% CI 1.00–1.03; SD 0.89 and ranging between −0.94 and 3.47 mm). In the total material, 49% of the implants lost more than 1 mm bone, 18% of the implants lost more than 2 mm, and but 5% lost more than 3 mm bone. A distinction was made per implant surface roughness and shown in Figure 3, A–C for rough, moderately or minimally rough surfaces and Figure 3D for the mixed/unknown surfaces. The mean bone loss, standard deviation and proportion of implants losing more than 1, 2, or 3 mm bone is given per study. Table 5 shows per surface roughness the mean bone loss pointing to 1.04 mm, 1.01 mm, and 0.86 mm for the rough, moderately, and minimally rough surfaces, respectively. Between minimally and moderately or rough there was a statistically significant difference, but this was not observed between moderately and rough surfaces. Taking bone loss above 2 mm as arbitrary cut-off point reflecting a higher chance for peri-implant disease, the proportion was 20% for rough (Figure 3A), 18% and for

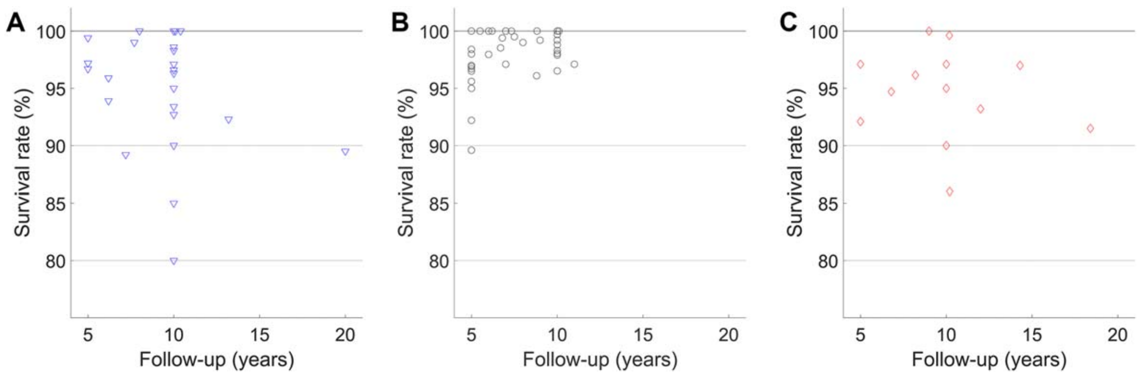

Figure 1 A. Implant survival in relation to loading time and surface roughness for rough surface implants. B. Implant survival in relation to loading time and surface roughness for moderately rough surface implants. C. Implant survival in relation to loading time and surface roughness for minimally rough surface implants.

moderately rough (Figure 3B), and 14% for minimally rough (Figure 3C).

Unfortunately among the 87 selected papers for this review, there was only one prospective study that compared machined minimally rough Brånemark implants with moderately rough TiUnite implants in conjunction with immediate loading.[147] The TiUnite surface yielded a superior cumulative implant survival of 95.5% compared to 85.5% in the machined group but the corresponding 1.4 and 1.7 mm bone loss was not statistically different. Unfortunately, this study did not report the standard deviation of the mean bone loss and hence could not be included in prevalence calculation.

There are four retrospective studies in this review that compared implants with comparable design, often from the same implant brand, but with different surface roughness.[117,154,177] Vandeweghe and colleagues[117] evaluated 197 Southern Implants with either smooth or minimally rough surface after 10 to 21 years of loading with the baseline at time of implant placement. Multivariate analysis demonstrated that the rougher surface yielded more peri-implant bone loss than the smooth surface implant. Prevalence of bone loss above 3 mm, as reported in Figure 3, B and C, was 20% versus 4%. Nevertheless, when combining bleeding and probing depth in the analysis only 4.1% of the implants were diagnosed with peri-implantitis. The other three studies and four study groups compare TiUnite moderately rough with machined minimally rough Brånemark implants.

Patient-Related Risk Factors

In the smoking group of the Sayardoust study,[154] as well as in the Arnhart study,[180] TiUnite showed a better outcome whereas in the Sayardoust the non-smokers group and the Jungner group[177] the machined implants led to less bone loss. In the study of Arnhart[180] 72% of the patients reported to smoke and also had a history of periodontal disease. This could also explain 89% of the machined surface implants with bone loss above

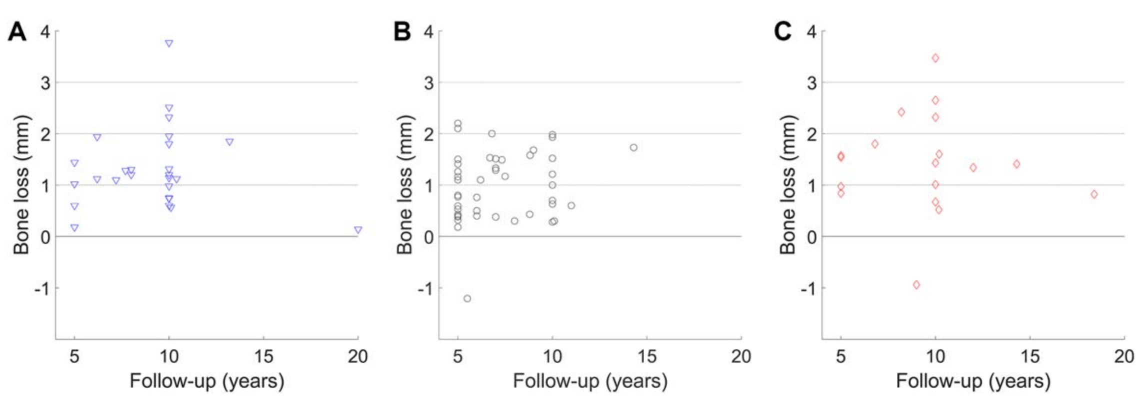

Figure 2 A. Bone loss (expressed as positive value in mm) in relation to loading time for rough surface implants. B. Bone loss (expressed as positive value in mm) in relation to loading time for moderately rough surface implants. C. Bone loss (expressed as positive value in mm) in relation to loading time for minimally rough surface implants.

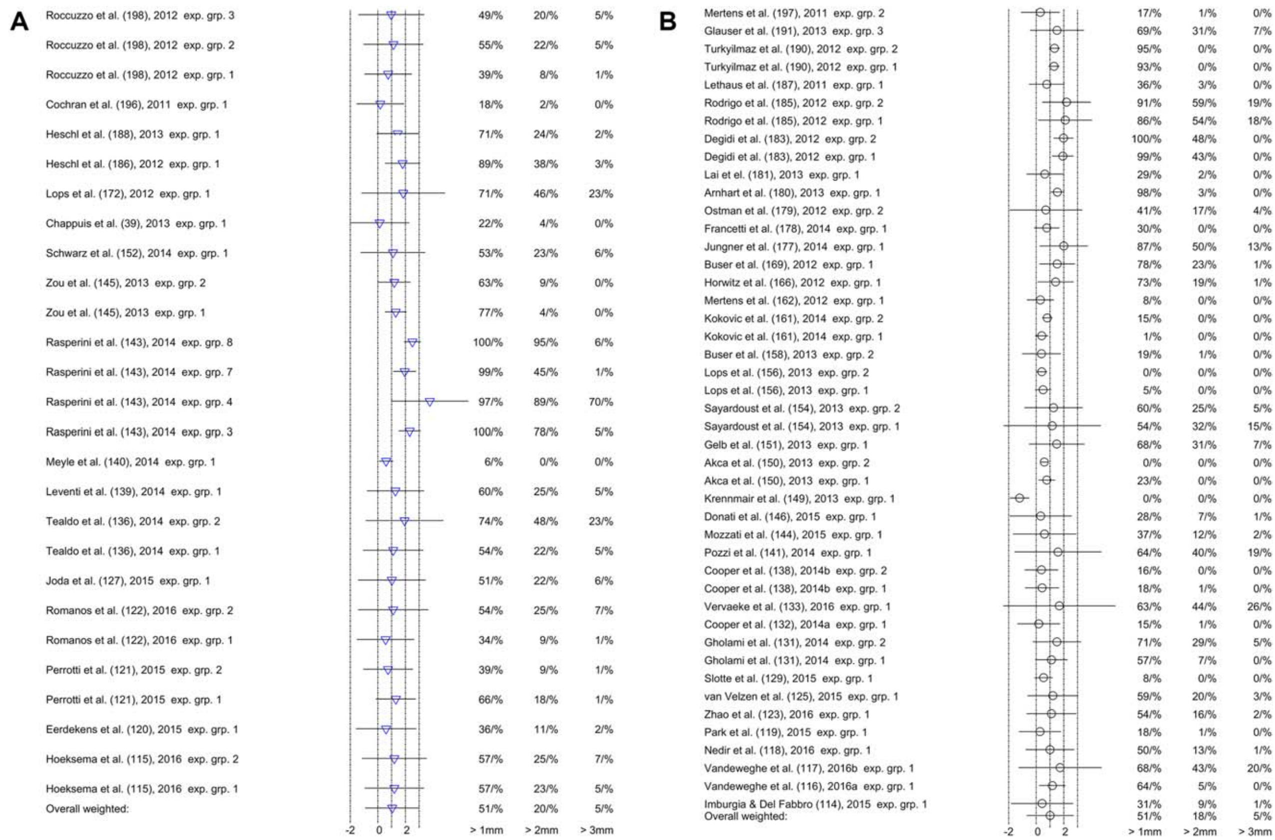

Figure 3 A. Clinical studies and bone loss (expressed as positive value in mm) for rough surface implants including proportions of implants with bone loss above 1, 2, or 3 mm. B. Clinical studies and bone loss (expressed as positive value in mm) for moderately rough surface implants including proportions of implants with bone loss above 1, 2, or 3 mm. C. Clinical studies and bone loss (expressed as positive value in mm) for minimally rough surface implants including proportions of implants with bone loss above 1, 2, or 3 mm. D. Clinical studies and bone loss (expressed as positive value in mm) for unknown/mixed surface implants including proportions of implants with bone loss above 1, 2, or 3 mm.

2 mm. For the meta-analysis the Arnhart study[180] was excluded because of the synergistic effect of smoking and periodontal history in a majority of cases.

Some papers assessed bone loss around similar implants and roughness in patients with various periodontal conditions. Roccuzzo and colleagues[198] demonstrated that periodontally healthy patients lost significantly less bone compared to patients with a history of moderate or severe periodontal disease. This outcome was also reflected by 8% versus 20% to 22% of the implants with bone loss above 2 mm, as can be seen in Figure 3A. Rasperini and colleagues[143] compared machined Brånemark surfaces and Straumann TPS surfaces after 10 years of function in four patient groups being either periodontally healthy or periodontally compromised and with or without smoking as cofactor (Figure 3, A and C). Bone loss above 2 mm was found in 89% to 95% of the implants placed in smokers, irrespective of the implant surface or the periodontal condition and in 78% of both implant types in periodontally compromised non-smoking patients. In the periodontally healthy and non-smokers, the TPS surface yielded 45% of the implants above 2 mm bone loss compared to only 7% in the machined smooth group. It seems that patient related risk factors affect bone loss to a bigger extent than surface roughness.

Meta-Analysis of Data

Heterogeneity. The estimated amount of total heterogeneity t^2 of all included study groups was equal to 0.54 (SE = 0.084). The variability explained through the variability between groups was significant and high $I^2 = 99.38\%$ ($Q = 13{,}950.7$, $df = 89$, $p < .001$). When the research groups were restricted to those with known surface roughness and inclusion or exclusion of smokers $t^2 = 0.56$ (SE = 0.093) was significant and the variability between groups remains high $I^2 = 99.36\%$ ($Q = 11{,}272.9$, $df = 76$, $p < .0001$). The roughness of the surface was significant as mediating factor

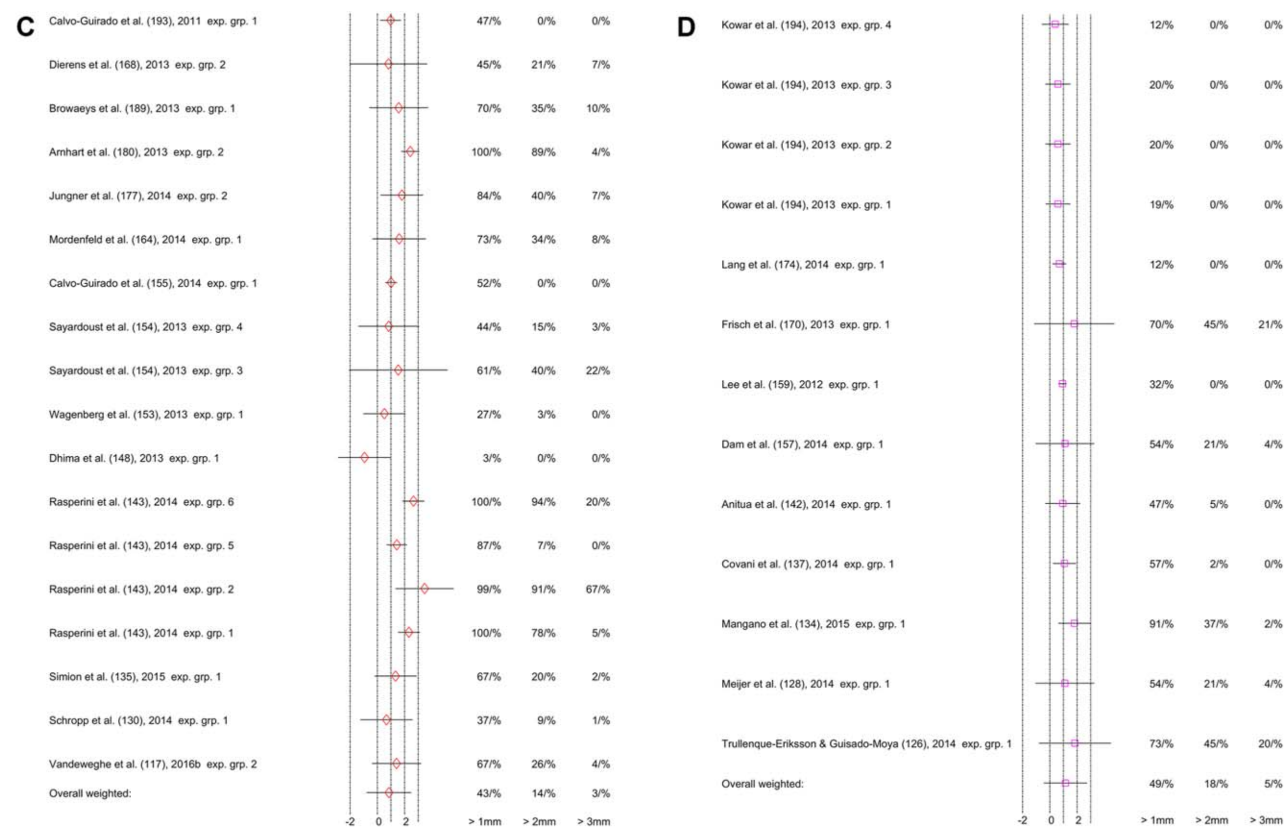

Figure 3 Continued

(QM = 7.43, df = 2, p = .024). The residual heterogeneity remained significant $t^2 = 0.5187$ (SE = 0.0878) and the variability between groups high $I^2 = 99.27\%$ (Q = 10,956.63, df = 74, $p < .0001$). The mediator roughness introduced a reduction in residual homogeneity of 0.09%. The inclusion of smokers in the study did not lead to a significant decrease in heterogeneity. Note that the inclusion of smokers does not mean that a research group solely consisted of smokers and that the amount of smoking was not taken into account because was seldom reported objectively.

Meta-Analysis. For studies testing differences in surface roughness using one implant design the heterogeneity I^2 between the studies was not significant (Q = 0.45, df = 2, p = .8001). The fixed effect model showed a significant difference in mean bone loss between minimally rough and moderately rough implant surfaces (Figure 4) with less bone loss for the former (z = 3.1716, p = .0015).

Heterogeneity $I^2 = 88.5\%$ for the studies evaluating the influence of periodontal history was significant equal to and the t^2 medium (66.6%) (Q = 32.55, df = 2, p = .0002). The random effects model showed a significant difference in mean bone loss between patient groups with a periodontal history and without a periodontal history (z = 2.1793, p = .029) (Figure 5). When only the rough surfaces were maintained the heterogeneity I^2 was no longer significant (Q = 1.76, df = 1, p = .1849). The random fixed effect model showed a significant difference with higher mean bone loss in patient groups with a periodontal history compared to periodontally healthy patients (z = 3.1822, p = .0015) (Figures 5 and 6).

Heterogeneity $I^2 = 90.8$ of the studies comparing smoking and non-smoking with respect to bone loss was significant (Q = 32.55, df = 3, $p < .0001$) and t^2 high (70.4%). The random effects model showed a significant difference in mean bone loss between smokers and non-smokers (z = 2.3008, p = .0214) (Figure 7).

DISCUSSION

This paper scrutinized the literature on peri-implant bone loss in relation to implant surface roughness.

TABLE 5 Summary of Implant Survival % and Mean Bone Loss (expressed as positive value in mm), Standard Deviation and Standard Error for Each Surface Roughness and Corresponding Proportion of Implants Estimated to lose bone >1 mm, >2 mm and >3 mm. *t*-Test was used for Statistical Comparison with p ≤ 0.05 Being Statistically Significant

Surface roughness	Mean bone loss (mm) [95% CI; SD; SE]	*t*-Test	Proportion % implants bone loss >1mm	>2mm	>3mm	Implant survival %
All studies	1.01 [1.00–1.03; 0.89; 0.0092]		49	18	5	97.3
Unknown surface	1.15 [1.11–1.19; 0.81; 0.021]	p=0.0002; p<0.00001; p<0.00001	49	18	5	95.8
Rough	1.04 [1.00–1.08; 1.01; 0.0189]	p=0.28; p<0.00001	51	20	5	96.4
Moderately rough	1.01 [0.98–1.04; 0.87; 0.0148]	p<0.00001	51	18	5	98.4
Minimally rough	0.86 [0.81–0.90; 0.84; 0.0212]		43	14	3	97.6

The main focus was on bone loss for two reasons. First, ongoing bone loss is a prerequisite in the diagnosis of peri-implantitis and second, stability of peri-implant bone is considered a crucial determinant for implant success.

Because the process of bone level changes due to disease may take some years before being diagnosed clinically,[199] a minimal 5 year follow-up was set as inclusion criterion. Furthermore, since most of the surface modified implants have been launched commercially at the time of the millennium change and the scientific community has started to show serious interest in the peri-implantitis issue after some consensus meetings dating back to 2006[200] and onwards,[40–43] the authors decided to limit the search to papers published over the last 6 years to increase the likelihood of finding relevant papers. This also seems logical because some extra time passes before clinical research is reported and published in scientific journals. It is important to recall that the studies selected in this review reflect daily reality and are not limited to strictly selected patient groups. It may be an advantage that the inclusion was kept as broad as possible to ensure that all types of clinical studies were included. Conversely, this approach may also yield criticism and voice opposition based on how the literature was chosen. It may also account for the heterogeneity of the studies.

During data analysis we struggled especially with the time point of the first radiographic assessment of the bone level, used as baseline for bone loss comparisons. Indeed, it is well known that peri-implant bone loss may be affected by the time point considered as baseline for the evaluation. There is consensus that a radiograph should at least be taken at the time of loading to register the bone level as baseline for future comparison to ensure that bone loss can be calculated.[43] Often this delayed assessment approach leads to an underestimation of the total bone loss because initial crestal bone remodeling is not included.[201] Different authors described initial crestal bone loss as a consequence of biologic width re-establishment after implant placement in patients with thin soft tissues.[19,202] Another effect on the crestal bone loss could be the microcap between the implant and abutment in 2 piece implants.[203,204] This crestal bone loss is not only caused by the size and location of the microgap but also by the movement of the implant components.[14,205]

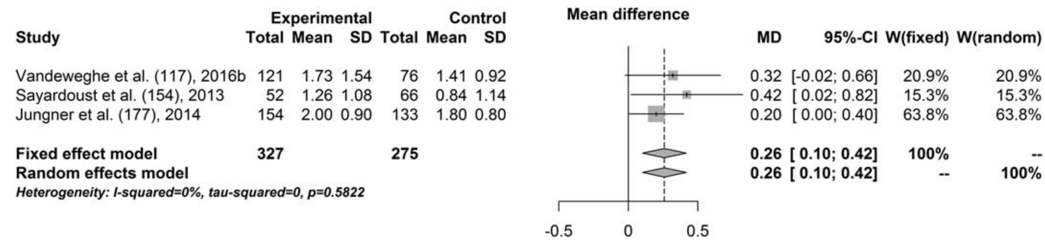

Figure 4 Forest plot for additional bone loss (expressed as positive value in mm) and moderately rough implant surfaces (experimental group) and minimally rough (control group).

Bacterial colonization of the exposed implant surface[206–208] may increase the risk for peri-implantitis. Vervaeke and colleagues[133] showed ongoing bone loss up to 9 years of function around implants with early bone loss in patients with other risk factors such as smoking and history of periodontitis.[133] Vandeweghe and colleagues[209] demonstrated that initial bone remodeling around immediately loaded implants occurs during the first 3 months in conjunction with biologic width establishment. Also with a one-stage surgery and delayed loading the soft tissue and bone healing starts at time of implant placement, yet this is not monitored when the baseline is taken at placement of the restoration several months later. For this review, however, we accepted the bone loss calculations based on a baseline at any given time point between implant installation and the first year. Additionally, it was impossible to control many other factors that may affect bone loss such as implant design, surgical technique, expertise level, prosthetic treatment protocols.[210] And last but not least, not all studies have the same follow-up time nor comparable patients' profiles with respect to risk factors such as smoking habits or periodontal history. It is our belief, however, that this flaw affects all studies irrespective of implant system or implant surface roughness and hence is of secondary importance in the context of the comparison of various surface roughness and its effect on bone loss.

One of the observations of the review was that very few papers actually report on peri-implantitis prevalence and those that do so often use different diagnostic thresholds or have incomplete data reporting and missing parameters. Only 6 papers of the 87 quoted all diagnostic parameters, suggested as essential to diagnose peri-implantitis.[43] This reflects that some studies yield extremely high "self-quoted" prevalence of peri-implantitis despite extremely low mean bone loss values,[140,163] which is indicative of low bone loss thresholds, whereas others have extremely low prevalence percentage despite contradictory high bone loss values.[163,189] These findings question the reliability of those self-reported prevalences, especially when incomplete data are presented, and point to the necessity of using more straightforward and objective parameters, such as bone loss over time. It can be concluded that researchers deliberately pay less attention to the assessment of parameters to diagnose peri-implantitis and that there is still no consensus on the criteria to define peri-implantitis.

By and large, the mean weighted bone loss ranged between 0 and 2 mm in 90% of the study groups (Figure 3, A–C). Only in 9/123 study groups (7.3%) was the mean bone loss above 2 mm as reported in 3 studies. However, since mean values may hide the real problematic cases, the statistical analysis using mean value and standard deviation

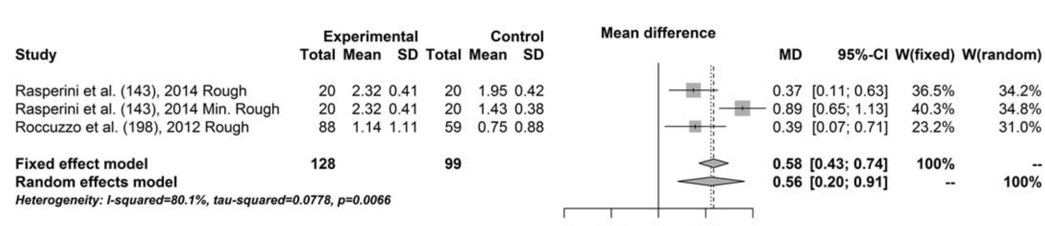

Figure 5 Forest plot for additional bone loss (expressed as positive value in mm) between patient groups with a periodontal history (experimental group) and without a periodontal history (control group) including one study using implants with a minimally rough surface and two studies using a rough surface.

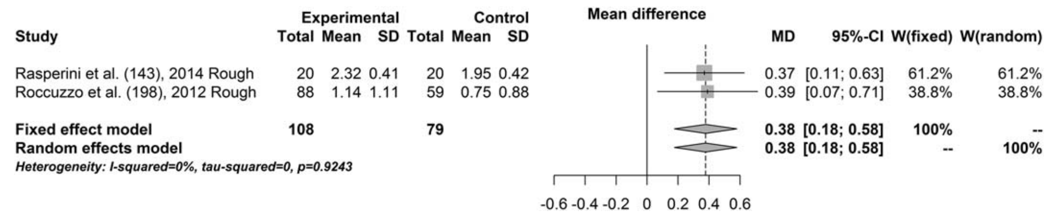

Figure 6 Forest plot for additional bone loss (expressed as positive value in mm) between patient groups with a periodontal history (experimental group) and without a periodontal history (control group) reduced to the two studies using implants with a rough surface.

allowed calculation of number of implants with an arbitrarily chosen bone loss threshold of above 1, 2, or 3 mm. We adopted the 2 mm bone loss threshold as proposed by Klinge and colleagues[211] since this could be suggestive of "risk-zone" cases.

The overall results demonstrate that 49% and 18% of all implants in the 87 studies lost more than 1 mm and 2 mm bone, respectively, during function above 5 years. It seems logical to conclude that setting a threshold for disease below this value is unrealistic and probably leads to false positive diagnosis of disease. Only 5% of the implants lost more than 3 mm bone. The proportion of implants losing above 2 mm bone is 14%, 18%, and 20% for minimally rough, moderately rough, and rough surfaces, respectively. Of course, the prevalence of 2 or 3 mm bone loss does not necessarily equals peri-implantitis. The approach applied in our paper may even overestimate the prevalence of peri-implantitis because bone loss should be accompanied by inflammation of the surrounding tissues as demonstrated by the presence of bleeding or pus. This explains why self-reported peri-implantitis prevalence (Table 4) does not always correspond with the prevalence of bone loss above 2 to 3 mm as reported in Table 3. The paper of Roccuzzo[198] demonstrates nicely that implants placed in patients with aggressive periodontal disease history have 15.1% peri-implantitis but only 1% of bone loss above 2 or 3. Meyle and colleagues[140] has no implants with bone loss above 2 mm yet finds 24% of peri-implantitis due to 27% bleeding. This seems suggestive of mucositis diagnosis instead of peri-implantitis. The parameters bleeding or the bone loss threshold taken for disease seem to have a very decisive effect in rocketing peri-implantitis upwards in many studies. Interestingly, in an 18-year follow-up study, Dierens and colleagues[212] demonstrated that bleeding on probing is a bad predictor for bone loss or peri-implantitis.

There is a statistically significant difference in the mean bone loss calculated between the various roughness groups with a trend for higher bone loss for the rougher implant surface (Table 5). Whether this is of clinical significance remains disputable taking heterogeneity of the studies into account. Furthermore, one should take into consideration a 0.3 to 0.5 mm measurement error when performing radiographic bone assessments.

Hence, a better approach is to compare implants with equal design but only differing in surface topography in prospective randomized controlled trials. Unfortunately, the only available prospective trial[147] was excluded because of missing standard deviation, required to do the statistics. The other three studies, albeit of retrospective design, were testing minimally rough surfaces and moderately rough surfaces with

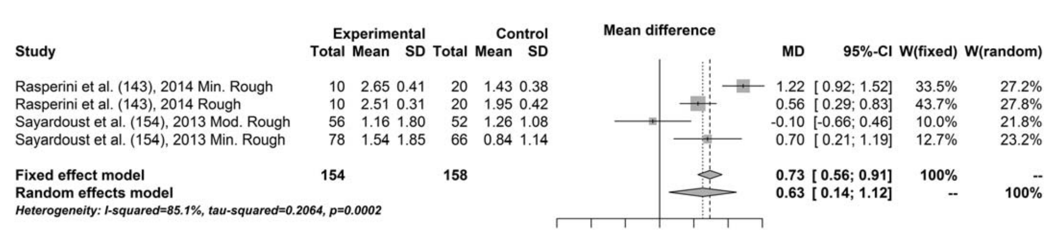

Figure 7 Forest plot for additional bone loss (expressed as positive value in mm) between smokers (experimental group) and non-smokers (control group).

similar implant designs. Hence, these three studies were apt for meta-analysis as shown in Figure 4. The minimally rough surface was statistically better in minimizing bone loss. However, the amount of studies is scarce and more research is required to confirm this finding.

CONCLUSIONS

Although rough surface implants induce statistically significant more bone loss according to the present meta-analysis, the clinical impact of surface roughness on bone loss is limited in the majority of the papers. The multifactorial cause for bone loss and the heterogeneity of the studies, related to inclusion of risk patients as well as poor data reporting, make it difficult to draw strong conclusions regarding the effect of implant surface roughness on bone loss over time. Nevertheless, independent of surface or implant brand, bone loss above 3 mm occurs in less than 5% of all implants after at least 5 years in function. Moreover, the meta-analysis indicates that co-factors such as smoking or periodontal disease increase the risk for bone loss.

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