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Long-term clinical outcome of implants with different surface modifications

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The aim of the present systematic review was to evaluate reported survival rate and marginal bone (MBL) loss of implants with different surface roughness and followed up for 10 years or longer. For the majority of the 62 included clinical studies, no direct comparison between different surfaces was made, thus our report is mainly based on reported survival rates and marginal bone loss for individual implant brands with known surface roughness. The survival rate was 82.9 to 100% for all implants after 10 or more years in function and the marginal bone loss was, on average, less than 2.0 mm for all implant surfaces included, i.e. turned, titanium plasma sprayed (TPS), blasted, anodised, blasted and acid-etched but the turned surface in general demonstrated the smallest MBL. However, the survival rates were in general higher for moderately rough surfaces. The roughest TPS surface demonstrated the highest probability for failure, while the anodised showed the lowest probability. In conclusion, the present systematic review demonstrates that it is possible to achieve very good long-term results with all types of included surfaces.

Introduction

In the 1980s, when implant treatment became a common option to rehabilitate edentulous or partially edentulous patients, the majority of marketed implants had a turned, or what was commonly called a machined surface. This surface is characterised by its anisotropic nature, i.e. a dominant direction of the surface structure exists, and a relative smoothness. An estimated average roughness (Sa) is 0.5 µm to 0.8 µm, depending on the size and sharpness of the cutting instrument and the measuring and evaluation techniques used.

Implants with a much rougher surface were on the market during the 1980s, namely titanium plasma sprayed surfaces (TPS) and surfaces coated with hydroxylapatite (HA). These surfaces were both isotropic, i.e. the irregularities are distributed evenly on the entire surface with no dominating direction. Sa value for TPS and the HA coated surfaces at that time were greater than 2 µm when measured with optical profilometers and evaluated after errors of form and waviness had been removed by a Gaussian filter. However, these early generation HA-coated implants soon demonstrated clinical failures due to delamination of the HA-coat. The bonding between the core metal and the HA-coat was too weak to withstand long-term load. Subsequently, rough (i.e. TPS and early HA coated with an Sa value above 2 µm)[1] implants were soon reported to cause severe marginal bone resorption and hence were another reason for implant failure[2,3]. These reports contributed to the TPS and the first generation of HA-coated implants disappearing from the market within a few years.

By the turn of the millennium, the turned surface had more or less been abandoned in favour of newer, moderately rough surfaces produced by blasting, etching (or combinations thereof), and oxidation techniques. The new surfaces were characterised by being isotropic and having an Sa value between 1.1 µm to 1.7 µm.

These new moderately rough surfaces were introduced to the market during the 1990s and early 2000s after numerous experimental *in vivo* studies had demonstrated that the blasted, blasted and etched, and oxidized surfaces all out-performed a machined (i.e. turned, milled or polished) surface in terms of faster and firmer osseointegration of the implant. A common explanation of these findings was that the increased surface provided with improved biomechanical bonding, thus the primary stability during healing became improved and the bone healing process could proceed undisturbed from micromotions that may otherwise had caused a soft tissue interface.

Later clinical studies have reported very good clinical outcomes for implants with a moderately rough surface, particularly for patients with compromised conditions[4]. However, it must be noted that many papers have a rather short follow-up period[5-8].

Although these publications call attention to the advantages of moderately rough surfaces, there are other opinions. Mainly based on animal experiments, concerns have been expressed as to whether the surface enlargement may cause increased marginal bone resorption similar to that found with the TPS/HA surfaces.

Compared with the machined surfaces, moderately rough surfaces were allegedly difficult to clean with normal oral hygiene procedures and therefore were more prone to harbour plaque and microbiota, which according to some authors can cause mucositis and subsequently induce bone resorption[9,10]. Anodised surfaces have been particularly incriminated in this context. However, the paper by Albouy et al[9] was a ligature study in animals, miles away from the clinical reality. The work by Derks et al[10] ignored the fact that anodised, hexed implants generally display 1.0 mm of MBL during the first year after implant placement[4], irrespective of any periodontal disease process, as defined by Lindhe and Meyle[11]. A recently published meta-analysis comparing clinical data from 43,680 turned and 23,306 anodised implants revealed a significant higher risk ratio for failure in the case of turned implants (RR 2.82, $P < 0.00001$), and no significant difference was found with respect to marginal bone resorption between the two implant surfaces[6].

To ascertain whether moderately rough surfaces perform clinically as well as or even better than the machined implants, randomised controlled long-term studies would provide incontrovertible evidence. Unfortunately, such comparative studies are very rare and the few that have been published demonstrate several confounding factors, such as different implant design, material, loading conditions, etc.

The aim of the present systematic review was to evaluate the long-term clinical outcome of various implant surfaces, irrespective of whether a direct comparison was undertaken between different surfaces, but by combining the data from multiple single studies as well to determine whether any surface demonstrated a significantly better outcome after more than 10 years in function. The primary outcome measures in the present review are implant failure (loss of implant) and marginal bone resorption.

Materials and methods

The present study followed the PRISMA Statement guidelines[12].

Objective

The purpose of the present systematic review was to assess the survival rate and marginal bone loss (MBL) of dental implants manufactured with different surface modifications and followed up for a minimum of 10 years. The focused question was elaborated by using the PICO format (participants, interventions, comparisons and outcomes): What are the clinical outcomes (implant survival rate and MBL around implants) of partially and totally edentulous patients undergoing prosthetic rehabilitation supported by dental implants followed up for at least 10 years and related to the surfaces of included implants?

Search strategies

An electronic search without time restriction for publications in English was undertaken in November 2016 in the following databases: PubMed/Medline, Web of Science, and ScienceDirect.

The following terms were used in the search strategies: ((((((((((implant[All Fields] AND surface[All Fields]) OR (rough[All Fields] AND surface[All Fields])) OR (smooth[All Fields] AND surface[All Fields])) OR (machined[All Fields] AND surface[All Fields])) OR (turned[All Fields] AND surface[All Fields])) OR (blasted[All Fields] AND surface[All Fields])) OR (oxidized[All Fields] AND surface[All Fields])) OR (etched[All Fields] AND surface[All Fields])) OR (coated[All Fields] AND surface[All Fields])) OR ((“plasma”[MeSH Terms] OR “plasma”[All Fields]) AND sprayed[All Fields] AND surface[All Fields])) AND ((((((“mortality”[Subheading] OR “mortality”[All Fields] OR “survival”[All Fields] OR “survival”[MeSH Terms]) OR (marginal[All Fields] AND (“bone diseases, metabolic”[MeSH Terms] OR (“bone”[All Fields] AND “diseases”[All Fields] AND “metabolic”[All Fields]) OR “metabolic bone diseases”[All Fields] OR (“bone”[All Fields] AND “loss”[All Fields]) OR “bone loss”[All Fields]))) OR (“peri-implantitis”[MeSH Terms] OR “peri-implantitis”[All Fields] OR “peri-implantitis”[All Fields])) OR (“peri-implantitis”[MeSH Terms] OR “peri-implantitis”[All Fields] OR (“peri”[All Fields] AND “implantitis”[All Fields]) OR “periimplantitis”[All Fields])) OR (“bone resorption”[MeSH Terms] OR (“bone”[All Fields] AND “resorption”[All Fields]) OR “bone resorption”[All Fields])) OR complication[All Fields])) AND ((“dental implants”[MeSH Terms] OR (“dental”[All Fields] AND “implants”[All Fields]) OR “dental implants”[All Fields] OR (“dental”[All Fields] AND “implant”[All Fields]) OR “dental implant”[All Fields]) OR ((“mouth”[MeSH Terms] OR “mouth”[All Fields] OR “oral”[All Fields]) AND implant[All Fields])) AND Clinical Trial[ptyp]

An additional manual search of related journals was conducted. The reference list of the identified studies and the relevant reviews on the subject were scanned for possible additional studies.

Inclusion and exclusion criteria

The inclusion criteria comprised clinical human studies reporting a clinical series of patients undergoing prosthetic rehabilitation supported by dental implants, and being followed up for a minimum of 10 years. When a study reported a follow-up range, the follow-up time had to be at least 10 years for the included implants. The publications needed to report detailed information on the implant system(s) used in the study, as well as the number of implants placed and failed for each implant system, if more than one system was used. Randomised and controlled clinical trials, cross-sectional studies, cohort studies, case-control studies, and case series were considered. Exclusion criteria were case reports and review papers.

Study selection

The authors independently read the titles and abstracts of all reports identified through the electronic searches. For studies appearing to meet the inclusion criteria, or for which there were insufficient data in the title and abstract to make a clear decision, the full report was obtained. Disagreements were resolved by discussion between the authors.

Data extraction

The authors independently extracted data using specially designed data extraction forms. These forms were piloted on several papers; these were modified as required before use. From the studies included in the final analysis, the following data was extracted (when available): year of publication, type of implant surface, study design (retrospective or prospective), follow-up time, number of patients, implant systems used, number of implants placed and failed, type of prosthetic rehabilitation, jaws receiving implants (maxilla and/or mandible), and MBL. For this review, implant failure represents the complete loss of the implant. Contact with authors for possible missing data was performed.

Analyses

Descriptive statistics were utilised to report the data. In order to standardise and clarify ambiguous data, the implant failure rate was reported for each publication. Implant failure and MBL were the outcome measures evaluated, and the statistical unit was the implant. Differences in failure rates between different implant surfaces were compared using the Pearson’s chi-squared or Fisher’s exact tests, depending on the number of samples in a 2 × 2 contingency table. The untransformed proportion (random-effects

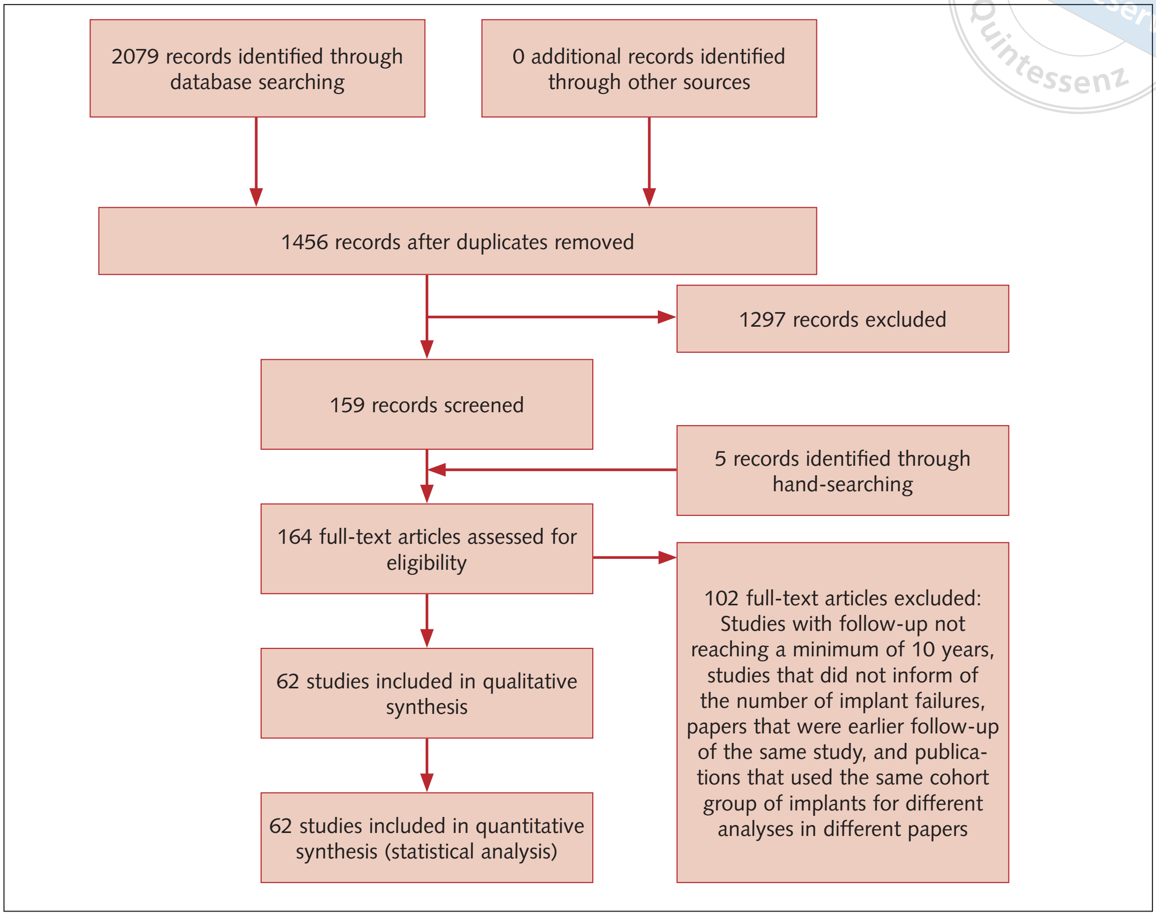


Fig 1 Study screening process.

DerSimonian-Laird method[13]) for implant failure was calculated, considering the different implant surfaces. Meta-regressions were performed for the outcome MBL for each group of implant surface, having the follow-up period as covariate. Statistical significance was set at $P < 0.05$. The data were analysed using the software OpenMeta[Analyst][14] and SPSS software version 23 (SPSS, Chicago, IL, USA).

Results

Literature search

The study selection process is summarised in Figure 1. The search strategy resulted in 2079 papers. In total, 623 articles were cited in more than one research of terms (duplicates). The reviewers independently screened the abstracts for those articles related to the focus question. Of the resulting 1456 studies, 1297 were excluded for not being related to the topic, resulting in 159 entries. Additional hand searching of the reference lists of selected studies yielded five additional papers. The full-text reports of the 164 articles led to the exclusion of 102 papers because they did not meet the inclusion criteria (studies with mean follow-up not reaching a minimum of 10 years, studies that did not inform of the number of implant failures, papers that were earlier follow-up of the same study, and publications that used the same cohort group of implants for different analyses in different papers). Thus, a total of 62 publications were included in the present review.

Description of the studies

Thirty-five prospective[15-49] and 27 retrospective studies[50-76] were included in the present review. Detailed data of the 62 included studies are listed in Table 1. The studies included turned (machined) implants, besides implants with blasted, acid-etched, sandblasted and acid-etched, anodised, titanium plasma-sprayed (TPS), sintered porous, and microtextured surfaces.

Table 1 Details of the 62 included studies.

Authors	Year	Follow-up (years)	Patients (patients followed up for 10+ years) (n)	Failed/placed implants (implants included 10+ years) (n)	Implants used to evaluate MBL (n)	Implant surface modification	Type of construction
Lekholm et al.	1999	10	127 (89)	34/461 (304)	304	Turned a	FPP
Lindquist et al.	1996	15	47 (45)	3/273 (258)	258	Turned a	FAF
Ekelund et al.	2003	20	NA (30)	3/273 (179)	179	Turned a	FAF
Jemt	2008	15	38 (28)	0/47 (32)	23	Turned a	SC
Bergenblock et al.	2012	18	57 (48)	2/65 (53)	44	Turned a	SC
Jemt	2009	10	35 (24)	0/41 (28)	28	Turned a	SC
Lekholm et al.	2006	20	27 (17)	9/112 (69)	69	Turned a	FPP
Hultin et al.	2000	10	15 (15)	0/55 (55)	55	Turned a	FPP
Naert et al.	2004	10	36 (26)	1/72 (52)	NA	Turned a	OD
Gunne et al.	1999	10	23 (20)	8/69 (52)	34	Turned a	FPP
Örtorp and Jemt	2009	15	208 (65)	9/821 (NA)	282	Turned a	FAF
Åstrand et al.	2008	20	48 (NA)	14/269 (NA)	116	Turned a	FAF
Leonhardt et al.	2002	10	15 (15)	3/57 (54)	54	Turned a	FAF, FPP
Roos-Jansåker et al.	2006	14	218 (10)	46/1057 (43)	43	Turned a	FAF, FPP
Sundén Pikner et al.	2009	20	640 (NA)	61/3462 (56)	56	Turned a	SC, FPP, FAF
Schnitman et al.	1997	10	10 (NA)	4/63 (14)	14	Turned a	FAF
Maló et al.	2011	10	245 (2)	13/980 (NA)	NA	Turned a	FAF
Turkyilmaz and Tözüm	2015	30	4 (4)	0/28 (28)	28	Turned a	FPP
Wagenberg and Froum	2010	11	78 (68)	11/106 (NA)	94	Turned a	SC, FPP
Naert et al.	2001	10	246 (NA)	11/668 (NA)	NA	Turned a	FPP
Nyström et al.	2009	10	44 (19)	27/334 (NA)	NA	Turned a	FAF
van Steenberghe et al.	2001	12	158 (NA)	5/316 (NA)	30	Turned a	OD
Attard and Zarb	2004	10	45 (22)	5/132 (86)	58	Turned a	OD
Attard and Zarb	2004	21	45 (32)	33/265 (87)	87	Turned a	FAF
Jemt and Johansson	2006	15	76 (25)	37/450 (150)	150	Turned a	FAF
Rocci et al.	2012	10	46 (NA)	9/97 (75)	75	Turned a	SC, FPP
Dierens et al.	2012	16	134 (97)	13/166 (121)	121	Turned a	SC
Östman et al.	2012	10	46 (46)	1/121 (120)	97	Oxidised b	SC, FPP, FAF
Degidi et al.	2012	10	59 (48)	5/210 (158)	158	Oxidised b	FPP
Mozzati et al.	2015	10	90 (NA)	6/209 (181)	181	Oxidised b	SC, FPP
Wagenberg and Froum	2015	11	312 (NA)	0/312 (NA)	6	Oxidised b	SC, FPP
Polizzi et al.	2013	10	244 (192)	23/500 (NA)	NA	Turned a Oxidised b	SC, FPP
Matarasso et al.	2010	10	80 (80)	6/80 (80)	80	Turned a TPS c	SC, FPP
Ravald et al.	2013	12	66 (46)	18/371 (345)	345	Turned a Blasted d	FAF
Jacobs et al.	2010	16	36 (NA)	1/95 (47)	29	Turned a Blasted d	FPP
Meijer et al.	2009	10	90 (76)	5/180 (152)	152	Turned a TPS c, e	OD
Meijer et al.	2004	10	61 (53)	13/122 (106)	NA	Turned a TPS e	OD
Vroom et al.	2009	12	40 (26)	3/80 (52)	52	Turned f Blasted d	OD
Ma et al.	2010	10	106 (79)	4/212 (158)	158	Turned a Sandblasted/ etched g, h Acid-etched i	OD
Telleman et al.	2006	10	60(38)	5/184 (115)	115	TPS c	OD
Simonis et al.	2010	10	76 (55)	22/162 (131)	131	TPS c	SC, FPP
Roccuzzo et al.	2010	10	126 (101)	18/246 (108)	108	TPS c	SC, FPP
Chappuis et al.	2013	20	98 (67)	10/145 (95)	95	TPS c	SC, FPP

Table 1 (cont.) Details of the 62 included studies.

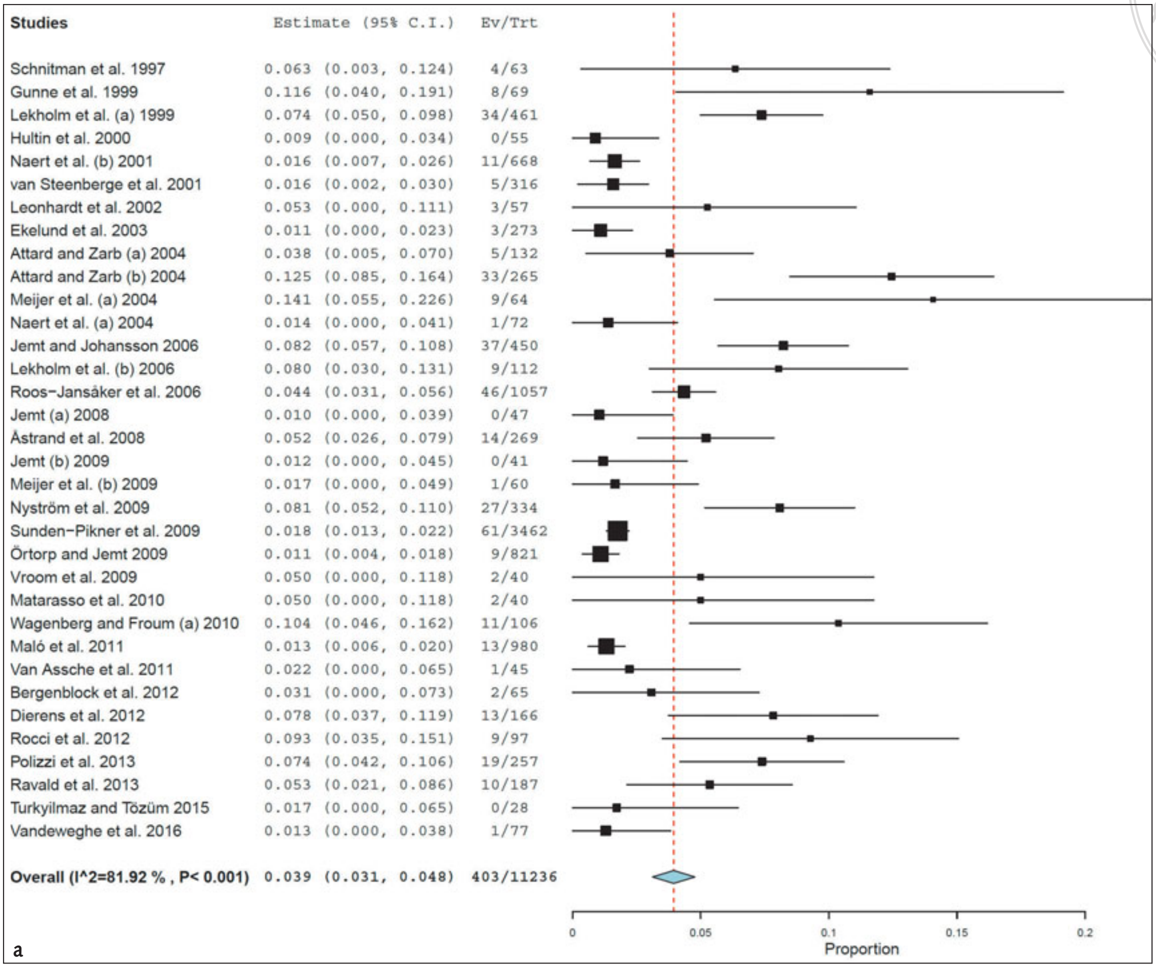
Karoussis et al.	2003	10	53 (NA)	5/112 (NA)	NA	TPS c	SC, FPP, FAF
Mericske-Stern et al.	2001	10	71 (71)	13/151 (132)	12	TPS c	SC, FPP, OD
Heckmann et al.	2004	10	41 (23)	0/82 (46)	46	TPS c	OD
Brägger et al.	2005	10	127 (89)	7/179 (176)	NA	TPS c	SC, FPP
Ferrigno et al.	2002	10	233 (NA)	16/1286 (24)	24	TPS c	OD, FAF
Ferrigno et al.	2006	12	323 (318)	9/588 (36)	36	TPS c Sandblasted/ etched h	SC, FPP, FAF
Buser et al.	2012	10	358 (303)	6/511 (511)	511	Sandblasted/ etched h	SC, FPP
Fischer et al.	2011	10	24 (23)	7/142 (102)	102	Sandblasted/ etched h	FAF
Rasmusson et al.	2005	10	36 (NA)	6/199 (NA)	NA	Blasted d	FAF
Mertens et al.	2012	11	17 (15)	3/108 (94)	94	Blasted d	FAF
Al-Nawas et al.	2012	10	108 (83)	53/516 (113)	113	Blasted d	FPP, FAF
Gotfredsen	2012	10	20 (20)	0/20 (20)	20	Blasted d	SC
Cecchinato et al.	2014	10	139 (100)	1¾07 (291)	291	Blasted d	FPP
Degidi et al.	2015	10	114 (80)	8/284 (193)	193	Blasted j	FPP
Krebs et al.	2013	20	4206 (NA)	319/12737 (NA)	NA	Blasted k Sandblasted/ etched k	SC, FPP, FAF
Vandeweghe et al.	2016	10	66 (NA)	6/203 (197)	197	Turned g Sandblasted/ etched g	FAF
Harel et al.	2013	10	23 (NA)	1/110 (NA)	NA	HA-particles blasted l	SC, FPP
Covani et al.	2012	10	91 (NA)	13/159 (146)	NA	Sandblasted/ etched m	SC, FPP
Deporter et al.	2012	10	24 (19)	2/48 (39)	39	Sintered porous n	FPP

MBL – marginal bone loss; NA – not available, TPS – Titanium plasma sprayed, SC – single-crown, OD – overdenture, FAF – full-arch fixed, FPP – fixed partial prosthesis; a Nobel Brånemark turned implants, Nobel Biocare, Göteborg, Sweden; b Nobel TiUnite implants, Nobel Biocare, Göteborg, Sweden; c ITI TPS implants, Straumann, Waldenburg, Switzerland; d Astra TiOblast, Astra Tech AB, Mölndal, Sweden; e IMZ TPS implants, Dentsply, Mannhein, Germany; f Astra turned implants, Astra Tech AB, Mölndal, Sweden; g Southern Implants, Irene, South Africa; h SLA implants, Straumann, Waldenburg, Switzerland; i Steri-oss, Nobel Biocare, Göteborg, Sweden; j XiVE, Dentsply Implants, Mannheim, Germany; k Ankylos, Dentsply Implants, Mannheim, Germany; l Screw-Vent MTX, Zimmer Dental, Carlsbad, USA; m Sweden and Martina, Due Carrare, Italy; n Endopore, Sybron Implant Solutions, Orange, USA

Analyses

In general, the cumulative survival rates (CSR) after a minimum of 10 years in function were high for the machined/turned, the blasted, the blasted+ acid etched and the oxidised implants. The machined/turned had an CSR range from 84.7% to 100%, the TPS surfaces ranged from 82.9% to 98.9%, the blasted implants from 89.7 to 95%, the blasted and etched implants from 95.1% to 98.9% and the oxidized from 96.6% to 99.2%.

Table 2 shows the number of implants placed and failed for each surface type, as well as the probability of failure according to the random-effects DerSimonian-Laird method[13] analysis (Fig 2 shows the forest plots for each implant type). Anodised and blasted surface implants showed the lowest and highest failure rates, respectively. Anodised and TPS surface implants showed the lowest and highest probability of failure, respectively. A direct comparison between implants of different surfaces (Table 3) showed that the turned implants presented a significantly different failure rate when compared to blasted and anodised implants, but did not differ in comparison to TPS and sandblasted/acid-etched implants. Anodised surface implants always showed statistically significant better survival rates than any other surface implant. Due to the inclusion of only one clinical study each, sintered porous (one failure, 110 implants, 0.90% of failure), acid-etched (four



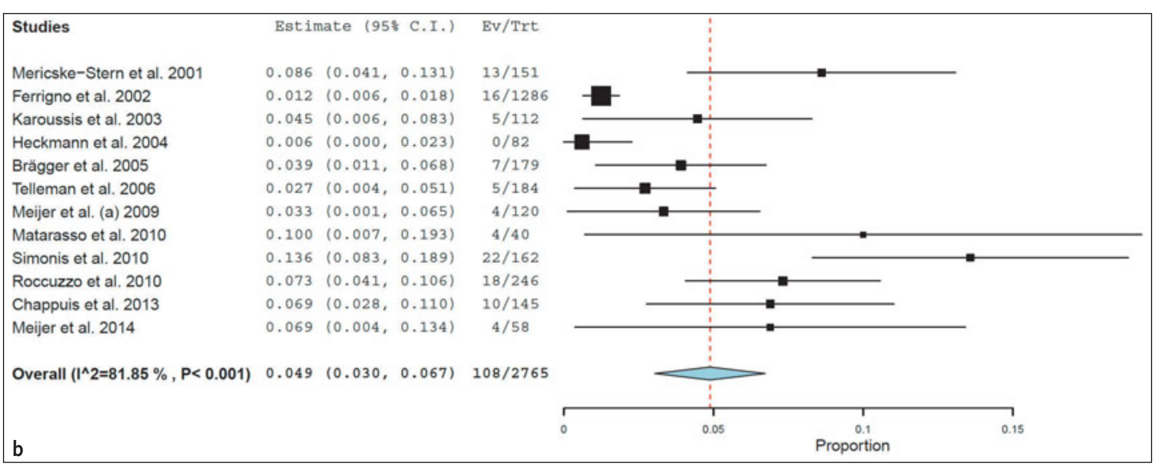
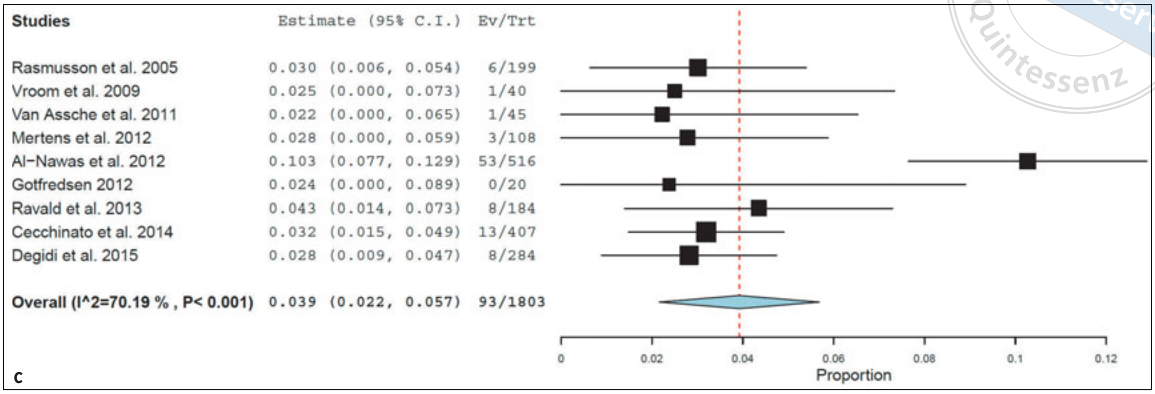


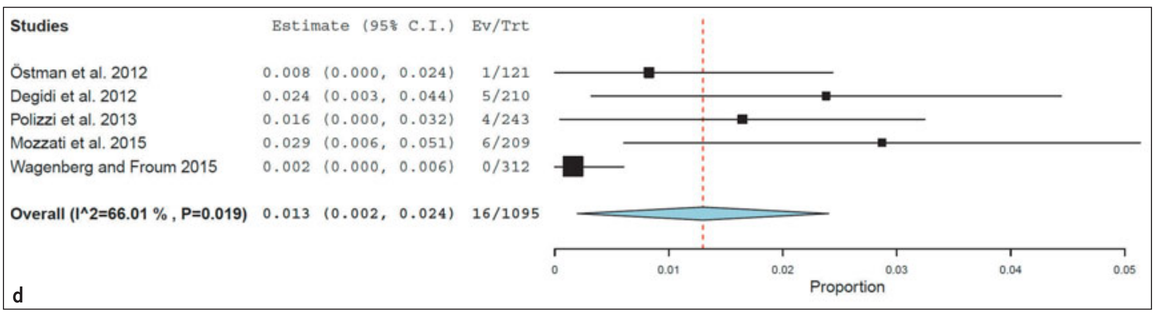
Fig 2 Probability of implant failure, based on studies of 10+ years of follow-up: a) turned; b) TPS; c) blasted; d) anodised; and e) sandblasted/acid-etched implants.

failures, 48 implants, 8.33% of failure), and micro-textured surface implants (two failures, 48 implants, 4.17% of failure) were not included in the analyses in Tables 2 and 3.

Thirty-six studies[17,19,21-23,25,29,30,32-36,38-40,42,44,45,47,48,50-53,56,57,62-64,66,67,69-71,74] provided information about the MBL separately by implant type, with mean and standard deviation. Blasted and turned implants showed the lowest MBL, while TPS implants demonstrated the highest values for MBL (Table 4). Figure 3 shows the forest plots concerning MBL, for each implant type.

Fig 2 (cont.) Probability of implant failure, based on studies of 10+ years of follow-up: a) turned; b) TPS; c) blasted; d) anodized; and e) sandblasted/acid-etched implants.





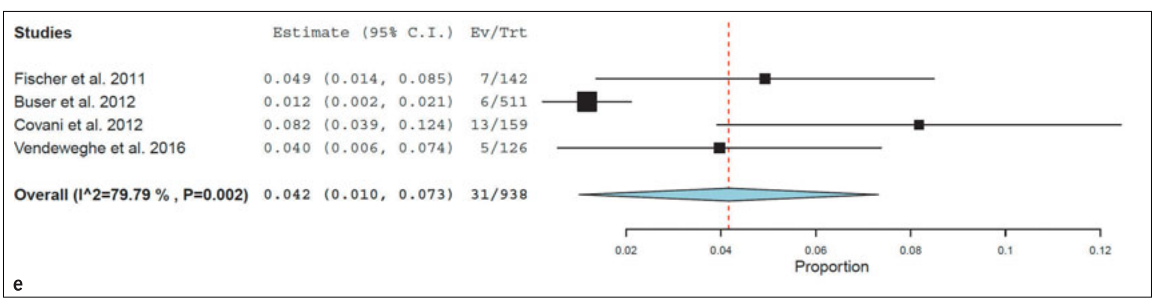


Table 2 Probability of implant failure for each implant type according to DerSimonian-Laird method.

Surface	Number of studies	Failure/total of implants (failure rate)	Probability of failure * (95% CI), *P* value	Heterogeneity
Turned	34	403/11236 (3.59%)	3.9% (3.1, 4.8), $P < 0.001$	$\tau^2 = 0.000$, $Chi^2 = 182.527$, $I^2 = 81.92\%$, $P < 0.001$
TPS	12	108/2765 (3.91%)	4.9% (3.0, 6.7), $P < 0.001$	$\tau^2 = 0.001$, $Chi^2 = 60.591$, $I^2 = 81.845\%$, $P < 0.001$
Blasted	9	93/1803 (5.16%)	3.9% (2.2, 5.7), $P < 0.001$	$\tau^2 = 0.000$, $Chi^2 = 26.838$, $I^2 = 70.192\%$, $P < 0.001$
Anodised	5	16/1095 (1.46%)	1.3% (0.2, 2.4), $P = 0.021$	$\tau^2 = 0.000$, $Chi^2 = 11.769$, $I^2 = 66.013\%$, $P = 0.019$
Sandblasted/ acid-etched	4	31/938 (3.30%)	4.2% (1.0, 7.3), $P = 0.010$	$\tau^2 = 0.001$, $Chi^2 = 14.844$, $I^2 = 79.79\%$, $P = 0.002$

5% CI – 95% confidence interval; TPS – Titanium plasma-sprayed

* Untransformed proportion, random-effects DerSim onian-Laird method

A meta-regression was performed having the follow-up time as covariate. It was possible to perform it with turned implants, due to the presence of enough data only for this implant surface. According to this statistical model, an increase of each year in follow-up time of turned implants results in an MBL gain of 0.022 mm (95% CI -0.069, 0.024) from an initial MBL loss of 1.168 mm after the first year of implant installation (Fig 4). The model, however, resulted in non-statistically significance ($P = 0.350$).

Table 3 Comparison of the differences in failure rates between different implant surfaces. If a significant difference, the implants with the lowest failure rate have been underlined.

Comparison	*P* value*
Turned vs TPS	0.423
Turned vs Blasted	0.001
Turned vs Anodised	< 0.001
Turned vs Sandblasted/acid-etched	0.655
TPS vs Blasted	0.044
TPS vs Anodised	< 0.001
TPS vs Sandblasted/acid-etched	0.403
Blasted vs Anodised	< 0.001
Blasted vs Sandblasted/acid-etched	0.027
Anodised vs Sandblasted/acid-etched	0.006

TPS –Titanium plasma-sprayed
*Pearson's chi-squared test

Discussion

The analysis of the results in this present review focused on implant surface modifications. However, this was not the main outcome measure reported in the majority of the studies; only a few linked the long-term clinical result to the implant surface and made comparisons of two or more surface modifications in their evaluation (Table 1). The study design and the main topic differed considerably between the included studies. Most of the studies reported long-term data on survival rates and marginal bone resorption for a specific implant brand over time and their position in the jaw (32 studies). Other studies reported on implant-supported overdentures (five studies), combined tooth/implant restorations (two studies), abutment material, cemented/screw retained constructions, framework material and platform switch (three studies), immediately loaded implants, implants in grafted bone and implants in fresh extraction sockets, flapless and non-submerged surgery (eight studies) and, finally, 12 studies whose main focus was on a particular implant surface. Furthermore, the included studies were published over a range of 20 years – 1996 to 2016 – during which time the indications for implant treatment have broadened and the number of treated patients with a compromised status has likewise increased. In addition, today many more practitioners are working with implants, as this is no longer a treatment only provided by specialists.

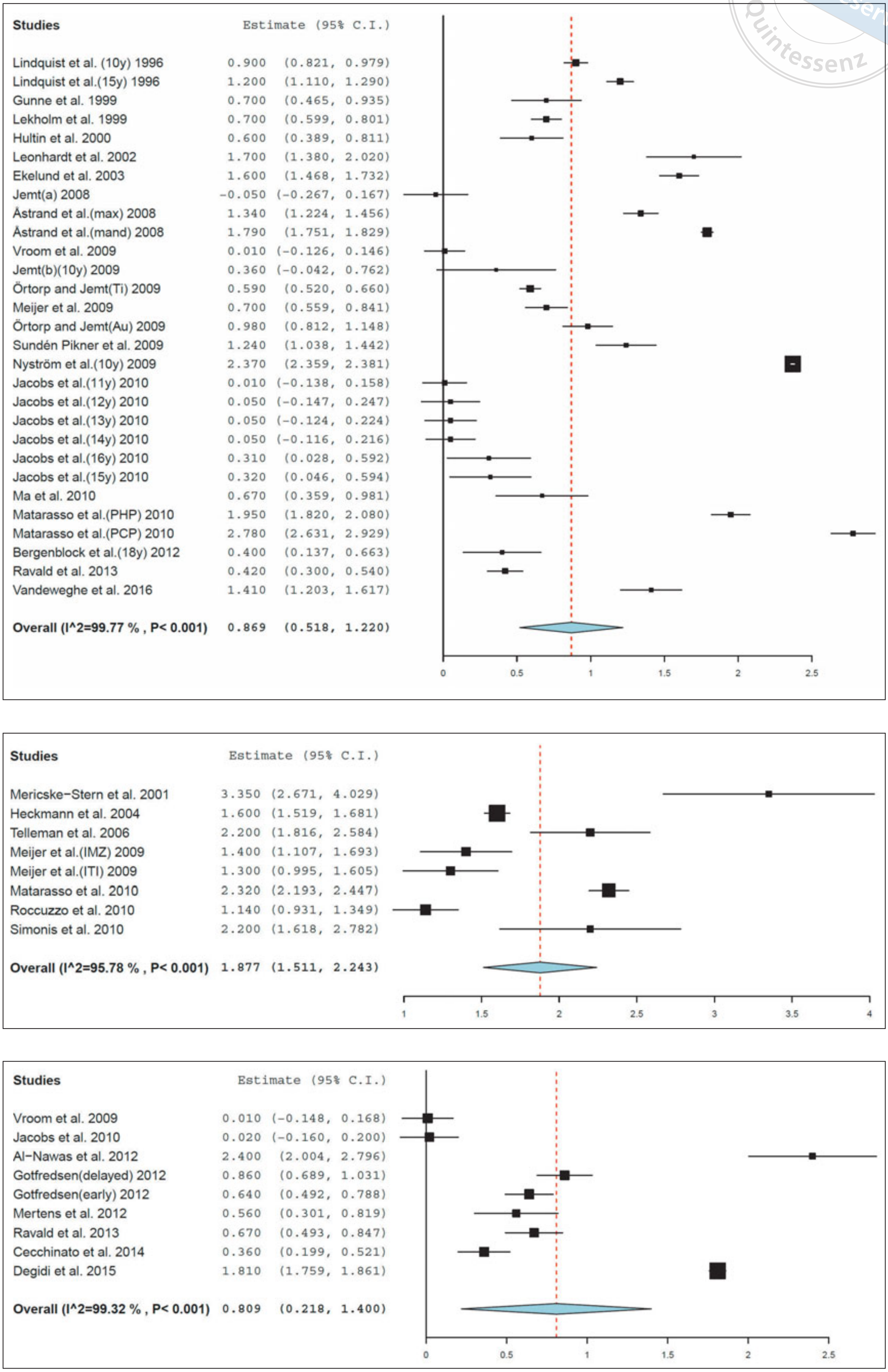
Table 4 Marginal bone loss, based on studies of 10+ years of follow-up.

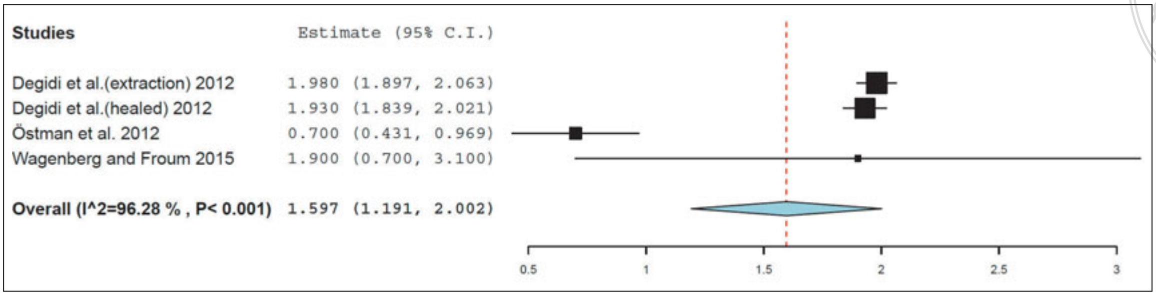
Surface	Number of studies*/ total of implants	MBL (in mm)** (95% CI), *P* value	Heterogeneity
Turned	20/2594	0.869 (0.518, 1.220), $P < 0.001$	$\tau^2 = 0.056$, $Chi^2 = 26866.249$, $I^2 = 99.855\%$, $P < 0.001$
TPS	7/556	1.877 (1.511, 2.243), $P < 0.001$	$\tau^2 = 0.245$, $Chi^2 = 165.779$, $I^2 = 95.778\%$, $P < 0.001$
Blasted	8/975	0.809 (0.218, 1.400), $P = 0.007$	$\tau^2 = 0.807$, $Chi^2 = 1181.421$, $I^2 = 99.323\%$, $P < 0.001$
Anodised	3/261	1.597 (1.191, 2.002), $P < 0.001$	$\tau^2 = 0.133$, $Chi^2 = 80.561$, $I^2 = 96.276\%$, $P < 0.001$
Sandblasted/ acid-etched	4/834	1.356 (-0.215, 2.927), $P = 0.091$	$\tau^2 = 3.204$, $Chi^2 = 2719.018$, $I^2 = 99.853\%$, $P < 0.001$

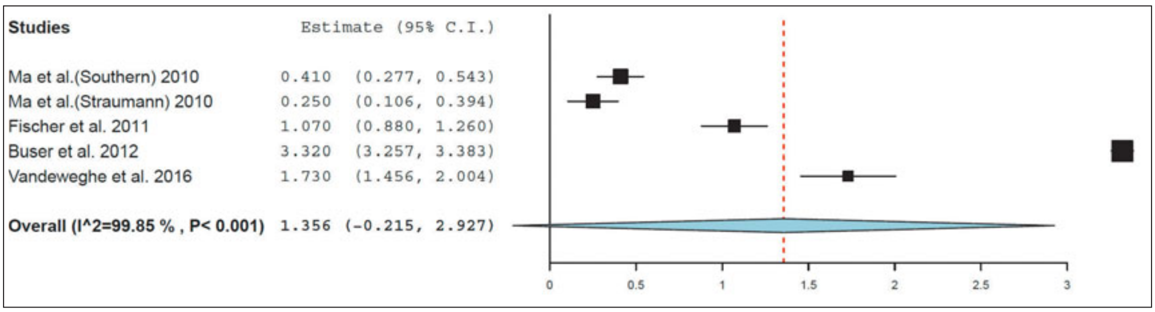
* Some studies may have included more than one implant surface.

**Negative value means bone gain.

Fig 3 Estimated marginal bone loss (MBL), based on studies of 10+ years of follow-up: a) turned; b) TPS, c) blasted; d) anodised; and e) sandblasted/acid-etched implants.







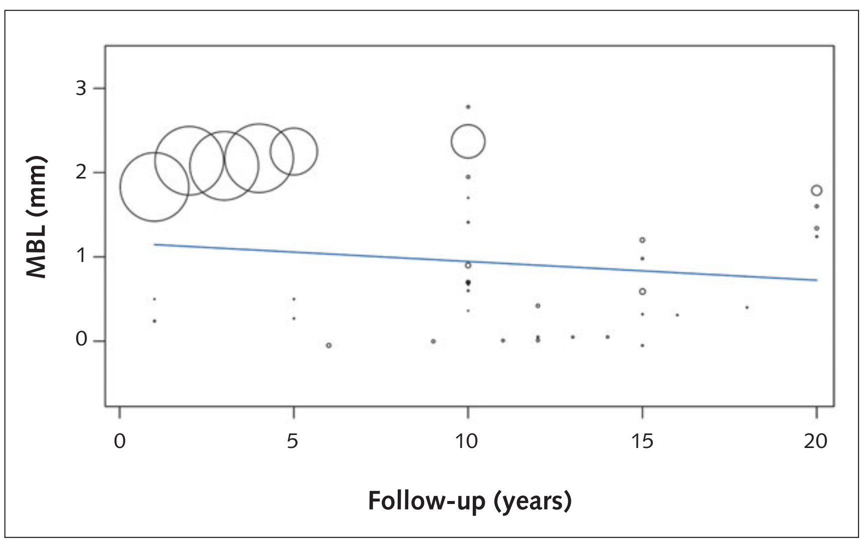


Fig 4 Scatter plot for the meta-regression: association between the marginal bone loss (in millimetres) of turned implants and the follow-up time (in years). Each circle represents marginal bone loss measurement of a group of implants from different studies, in different time point of follow-up. The size of the circles represents the weight of the study (from a meta-analysis point of view). Only studies with a minimum of 10 years of follow-up were considered. The line represents the estimated marginal bone loss along the years of observation.

The results of the present review suggest that the probability of failure for anodised implants is lower than that for turned implants, which was also a finding in a recent review comparing these two implant types[6], or any other enhanced-surface implant (see Table 2). The reason for this finding may be that the oxidized surface provides a greater number of undercuts that may result in improved osseointegration.

The lack of a statistically significant difference in failure rates between sandblasted/acid-etched implants and both turned and TPS implants (Table 3) could be a real effect or could be related to the low number of publications (n = 4) reporting failure rates for sandblasted/acid-etched implants. As implant survival rates are generally high, sample sizes need to be large to demonstrate statistically significant differences to infer a meaningful clinical difference in implant survival performance[77]. However, the number of publications (n = 5) – and the number of implants in these studies (n = 1095) – including and reporting failure rates for anodised implants, was quite similar to the ones evaluating sandblasted/acid-etched implants (four publications and 938 implants), the statistical analysis showed that anodised implants performed significantly better when compared with any of the other implant surfaces.

When considering marginal bone loss, most of the implants with an enhanced surface demonstrated a poorer prognosis in comparison to turned implants. This difference may be related to different sample sizes – as there were far more studies and implants evaluating MBL around turned implants than studies assessing enhanced-surface implants, the figures for turned implants may more reliably reflect the reality. Thus, additional long-term studies assessing MBL around enhanced-surface implants are necessary to obtain a larger sample size and provide a more reliable statistical comparison with turned implants. Moreover, data may be criticised as evidenced in the study by Jimbo and Albrektsson[4], which showed a similar increase in marginal bone loss with anodised implants after 5 or more years in function.

However, the difference was shown to occur in the first year after implantation, with no differences between the different implant surfaces between 1 and 7 years of follow-up. The hex design has been incriminated as the reason for this early marginal bone loss, which according to the definition by Lindhe and Meyle[11], is not an example of peri-implantitis.

Today implant treatment is a common treatment option not only for the specialised team, but for a larger number of general dental practitioners, some of whom may only perform a few cases per year, which will naturally make it difficult to maintain a high skill in this fast-developing discipline. In addition, more complicated surgical techniques have been adopted, often in combination with new 3D techniques such as flapless surgery, immediate loading, various grafting techniques, and implant placement in fresh extraction sockets are all factors that may contribute to the long-term clinical outcome. Thus, it is difficult to determine the precise influence of surface modifications when there are so many confounding factors. This is, of course, a limitation with the present evidence. However, the results indicate that it is possible to achieve very good long-term clinical results with all types of surfaces included in the present systematic review.

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